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MICROCOPY RESOLUTION TEST CHART

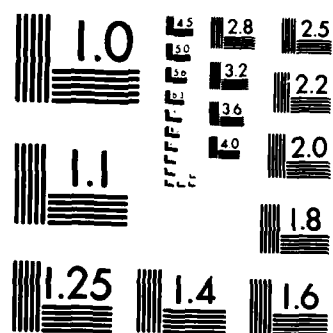NATIONAL BUREAU OF STANDARDS-1963-A

(12)

DAEDALEAN, Incorporated

ENGINEERING, DESIGN AND ANALYSIS SERVICES

FEASIBILITY INVESTIGATION OF
UTILIZING THE INTERNAL FRICTION
DAMPING NONDESTRUCTIVE EVALUATION
TECHNIQUE (IFD-NDE) FOR MEASURING
THE DEGREE OF FATIGUE IN MOBILE
BRIDGE STRUCTURES

Submitted to:

U. S. Army Belvoir Research
and Development Center
Attn: Brian K. Hornbeck (STRBE-NBC)
M/F: Contract No. DAAK70-84-C-0030
Fort Belvoir, Virginia 22060

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TECHNICAL REPORT

FEASIBILITY INVESTIGATION OF
UTILIZING THE INTERNAL FRICTION
DAMPING NONDESTRUCTIVE EVALUATION
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By

Robert S. Weinreich

This work was performed under
Contract No. DAAK70-84-C-0030

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The views, opinions, and/or findings contained in this report are
those of the author and should not be construed as an official
Department of the Army position, policy or decision, unless so
designated by other documentation.

DAI Technical Report No.
RSW-8409-001-TR

November 1984

SUMMARY

This report discusses a nondestructive test technique which has the potential for measuring the degree of fatigue in military bridge structures. The technique is called Internal Friction Damping Nondestructive Evaluation (IFD-NDE). The physical property that is monitored in this technique is the rate at which an energy impulse imparted to a material or structure decays due to the internal friction of the material. A change in the rate of decay reflects changes in the basic chemical and/or mechanical properties of the material due to an accumulation of subtle material variables. These material variables include the grain size, chemical compositions, interstitial elements, dislocations, precipitate particles, strain rate effects, etc.

By proper monitoring of the accumulation of these variables it has been shown in some materials to be possible to predict the remaining fatigue life before failure occurs.

It was the objective of this program to adapt the IFD-NDE technique to military bridges by first identifying the characteristic damping coefficient versus fatigue life curve for bar specimens of the materials used in the bridges.

The results of the work generally show that for the 6061 and 7075 aluminum alloys, the damping coefficient remains fairly constant until a point of approximately 30 percent remaining material life where a noticeable spike occurs in the data. Afterwards the damping coefficient returns to a nominal value. For the 7005

aluminum alloy, no correlation was found between the remaining
fatigue life and the damping capacity.

PREFACE

This work was performed under the Small Business Innovative Research Program and administered by the U. S. Army Belvoir Research and Development Center in Fort Belvoir, Virginia.

The procuring instrument identification number (PIIN) for this program was DAAK70-84-C-0030.

The author gratefully acknowledges the technical advice and assistance of the Contracting Officer's Technical Representative (COTR), Mr. Brian K. Hornbeck (STRBE-NBC).

TABLE OF CONTENTS

DAEDALEAN, Incorporated

v

LIST OF FIGURES

Page

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

FEASIBILITY INVESTIGATION OF
UTILIZING THE INTERNAL FRICTION
DAMPING NONDESTRUCTIVE EVALUATION
TECHNIQUE (IFD-NDE) FOR MEASURING
THE DEGREE OF FATIGUE IN MOBILE
BRIDGE STRUCTURES

1.0   INTRODUCTION

The use of mobile modular bridges which can be quickly trans-
ported to a needed location and easily set up is crucial to the
transport of men and material under combat conditions. Because
of the need of these bridges to be light in weight however, de-
sign safety factors used in their design are generally smaller
than those which might be used in a permanent bridge structure.
The fatigue life of mobile bridges will also be correspondingly
less.

It is prudent therefore to develop a means of directly mea-
suring the degree of structural fatigue present so that bridge
sections with little remaining fatigue life can be removed from
service. It is important however that the means to measure fa-
tigue life be functional in the typical environments experienced
by military bridges.

A nondestructive test technique which has the potential for
measuring the degree of fatigue in mobile structures has been
identified by DAEDALEAN, Incorporated (DAI). The technique is
called Internal Friction Damping Nondestructive Evaluation (IFD-NDE).

The physical property that is monitored in this technique is
the rate at which an energy impulse imparted to a material or

structure decays due to the internal friction of the material.
A change in the rate of decay reflects changes in the basic chem-
ical and/or mechanical properties of the material due to an ac-
cumulation of subtle material variables. These material variables
include the grain size, the chemical composition, interstitial
elements, dislocations, precipitate particles, strain rate effects,
etc.

By proper monitoring of the accumulation of these insidious
variables, it is possible to predict the remaining useful life
of many materials before a failure occurs.

Figures 1 and 2 show the basic laboratory equipment utilized
in the measurement of internal friction damping. A sine generator
(A) is used to drive an electromagentic shaker (B). When the
energy to the shaker is cut off, the decay of energy within the
specimen is monitored by a piezoelectric accelerometer (C). The
signal from (C) is sent to a frequency analyzer (D) where the
signal is filtered and amplified. The actual decay is observed
on a storage oscilloscope.

Figure 3 shows the typical change in a rate of energy decay
for a specimen as it nears a failure point. Figure 4 shows the
typical IFD-NDE response of a specimen exposed to fatigue load-
ing. The vertical axis of Figure 4 shows the specific damping
capacity $\left(\frac{\Delta W}{W}\right)$ which is a number that describes the rate of energy
decay. The horizontal axis shows the number of fatigue cycles.
Early in the specimen's fatigue life the $\frac{\Delta W}{W}$ is slowly increasing.
Later in the specimen's fatigue life the $\frac{\Delta W}{W}$ increases dramatically.

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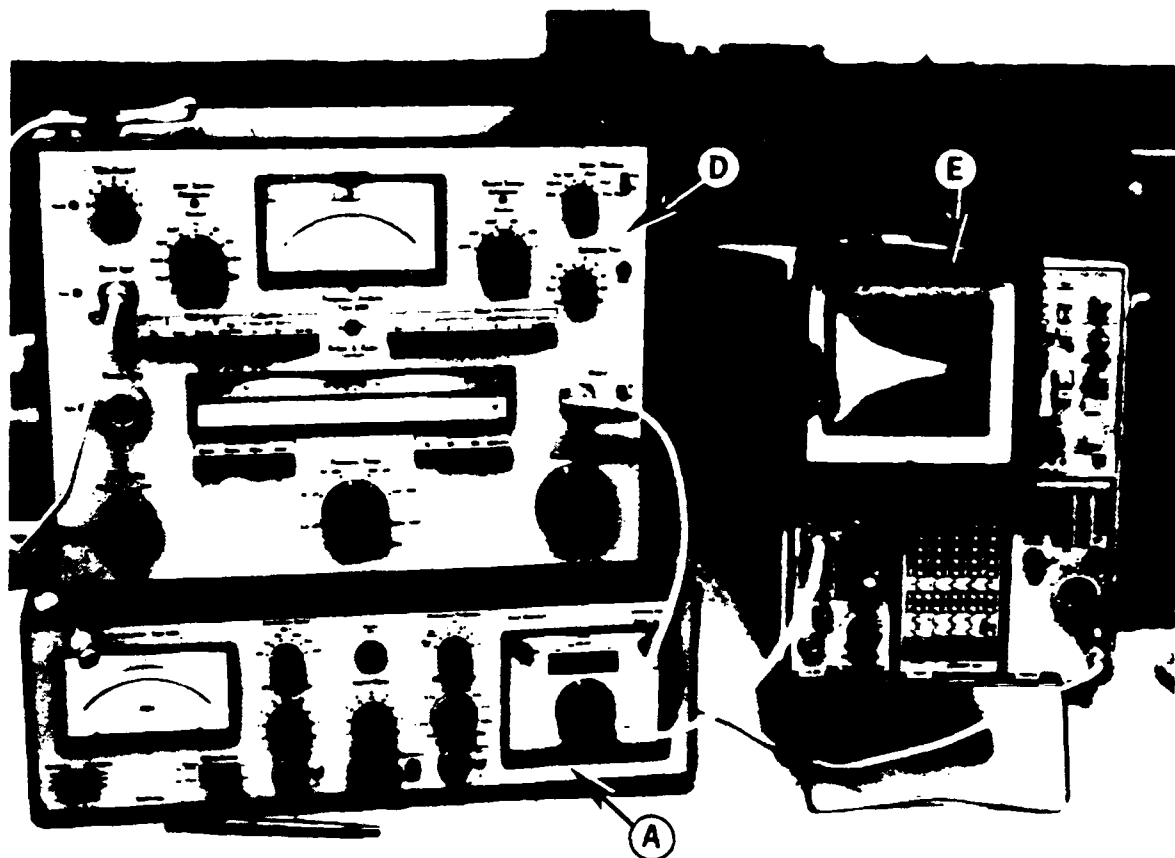
FIGURE 1 ANALYSIS EQUIPMENT UTILIZED IN THE IFD-NDE TECHNIQUE
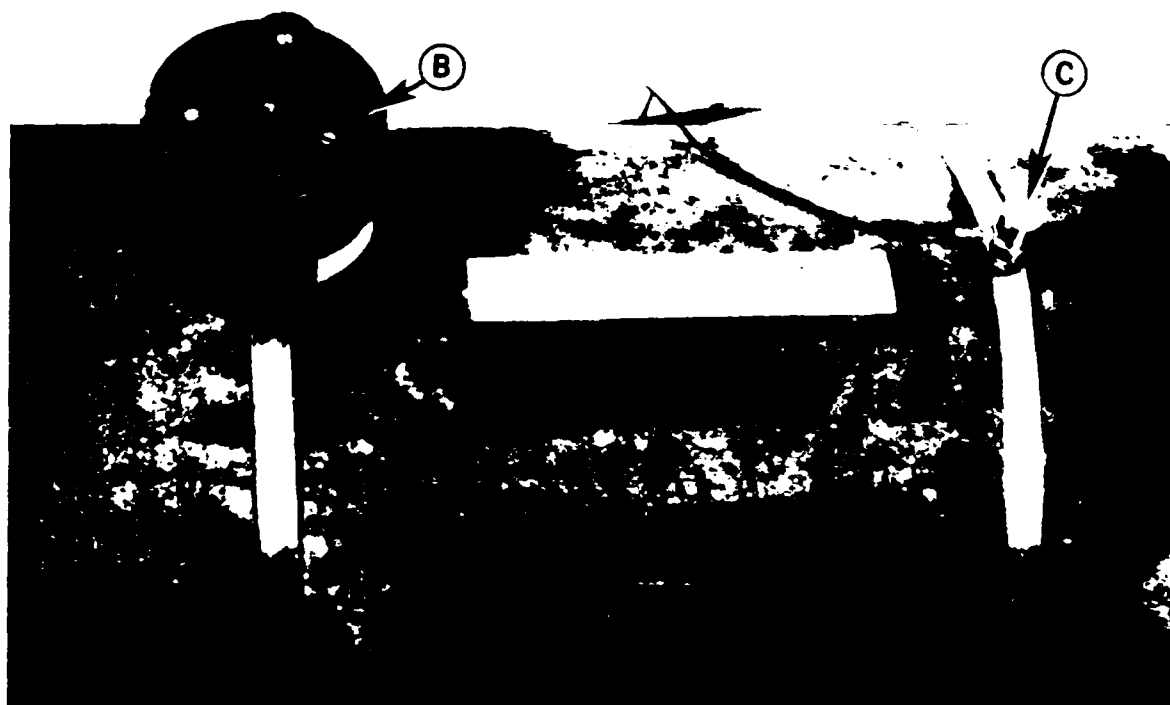
FIGURE 2 ELECTROMAGNETIC SHAKER AND PIEZOELECTRIC ACCELEROMETER UTILIZED IN IFD-NDE TECHNIQUE

2518-1

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DETECTION OF INCIPIENT FAILURE BY THE INTERNAL FRICTION NONDESTRUCTIVE EVALUATION METHOD

NOTE CHANGE IN DECAY ENVELOPE
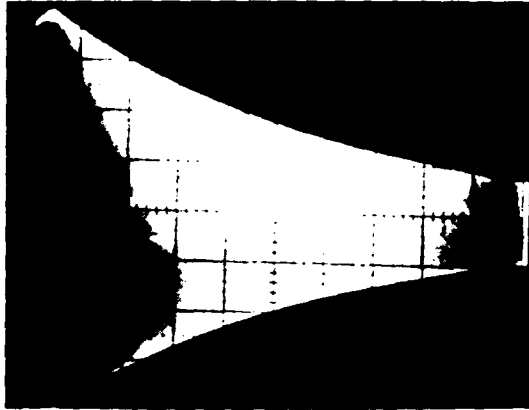
DECAY CURVE FOR UNDAMAGED MATERIAL   DECAY CURVE FOR INCIPIENT CRACK FORMATION
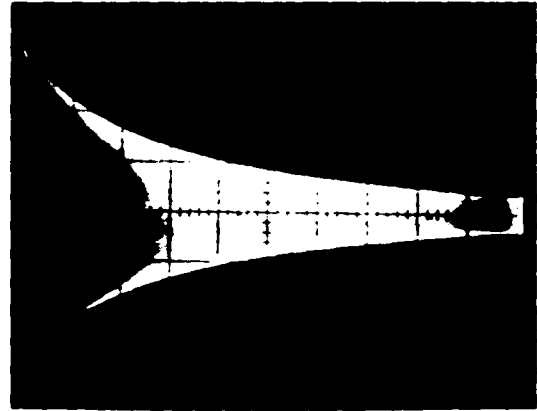
FIGURE 3 REPRESENTATIVE DAMPING DECAY CURVES INDICATING CHANGES IN INTERNAL FRICTION FOR INCIPIENT CRACK DETECTION

- ● ACTUAL VALUES
- — MEAN
- △ STATISTICAL UPPER CONFIDENCE LEVEL (99.0 %)

NOTE: LARGE INCREASE IN DAMPING PRIOR TO VISUAL CRACK

CRACK OBSERVED

BAR FAILURE - END OF TEST

SPECIFIC DAMPING CAPACITY ($\frac{\Delta W}{W} \times 10^{-4}$)

CYCLES × 1000
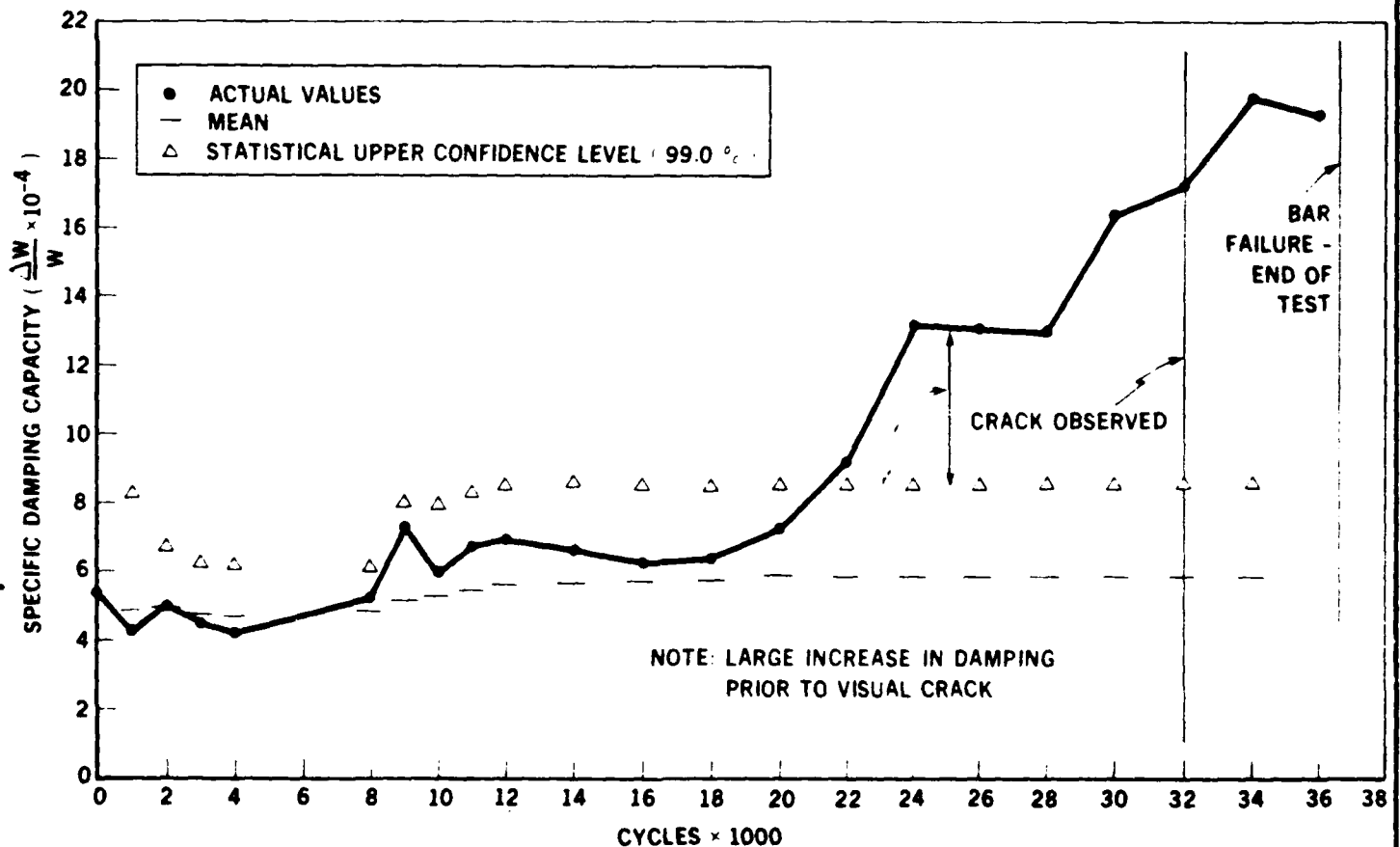
FIGURE 4   EXAMPLE OF SPECIFIC DAMPING CAPACITY VS FATIGUE CYCLES

If the specific damping capacity versus fatigue cycle history of bridge material is determined in a similar fashion as that seen in Figure 4, it would be possible to determine the remaining fatigue life of the bridges.

Since the damping capacity of a material is a bulk material property, differences in geometry are thought to have little effect on the damping capacity and so the technique can be applied to any shape or mass of a given material.

This technique could be easily adapted for field use since the process can be computerized by changing the electrical signal transmitted by the accelerometer into a digital signal. All the equipment necessary to perform the test and reduce the signal to a number describing the remaining fatigue life of a bridge could be put into a microprocessor which would fit in a backpack. In such a form, the inspection process could be performed by a non-technical person in the field who places the accelerometer and shaker mechanisms onto the bridge, initiates the process by pressing a go button and records the damping coefficient number of the particular section being observed as displayed on a digital read-out. Other advantages of the technique include:

- The technique does not have to be active during the occurrence of the failure mechanism.
- The technique will work in the presence of background noise.
- The technique can be computerized so that the

evaluation is not left to the subjective judgment
of the operator.

- It is not necessary to disassemble the component
  during evaluation.

- The ability to sense incipient failure zones at
  locations remote from the actual failure location.

- The ability to detect failures before they occur.

2.0   TECHNICAL APPROACH

The technical approach for this program was to determine the base line damping coefficient response of bar specimens of various bridge material in the laboratory after various levels of fatigue loading. The output of this work was a series of graphs relating the damping coefficient to the fatigue life for the particular alloy being tested.

3.0   INVESTIGATION

Figure 5 shows a picture of the fatigue device constructed for the work. The device utilizes a hydraulically actuated cylinder to impose a given load upon bar specimens which are located within a holding fixture on the device. The loading occurs in three point fashion with the supports on 12 inch centers and the load point midway between the centers. All contact points are radiused and therefore the bar specimens are free to rotate about the contact points upon loading.

The estimated load to which the bar specimens were exposed were arrived at in the following fashion:

The formula for the maximum stress of a bar specimen in the bending mode is

$$S = \frac{MY}{I}$$

where: S = Stress (psi)

M = Bending moment (lb. in.) = $\frac{PL}{4}$ for this case

where: P = load (lb.)

L = distance between support points (in.)

$\frac{Y}{I}$ = section modulus (in³) = $\frac{bh^2}{6}$ for this case

where: b = width of bar specimen (in.)

h = height of bar specimen (in.)

By substituting and rearranging the following equation is arrived at:

$$P = \frac{SBH^2}{18}$$

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FIGURE 5 BAR SPECIMEN CYCLIC FATIGUE DEVICE

8409-1

Since most available data indicated a yield strength for the alloys used in this program of 42,000-44,000 psi, 38,000 psi was selected as an initial stress level.

Thus:

$$P - 2111 \, BH^2$$

The bar specimens utilized were 1 inch high by 2 inches wide, thus the total initial load employed was 4,222 lbs. Subsequently, it was found that a load level of approximately twice this was necessary to get a failure to occur in a reasonable number of load cycles (10,000 - 15,000 cycles).

Three types of aluminum alloys were evaluated under this program, those being 7005-T53 and 6061-T6 and 7075. After each 1,000 cycle interval, the specimen being evaluated was removed from the load fixture and a damping coefficient was determined.

Figure 6 shows the experimental arrangement for performing the IFD-NDE measurement. The bar specimen is seen in the foreground. The device bearing upon the right end of the bar speciment is an electromagnetic shaker which was used to excite the specimen at a particular frequency.

The device attached to the middle of the specimen is a piezoelectric accelerometer by which the decay signal of the specimen is monitored. The accelerometer was coupled to the specimen by gluing a 10-32 flathead screw to the surface of the specimen with a fast setting adhesive. The accelerometer has a mating 10-32 threaded hole. The electronic device at bottom
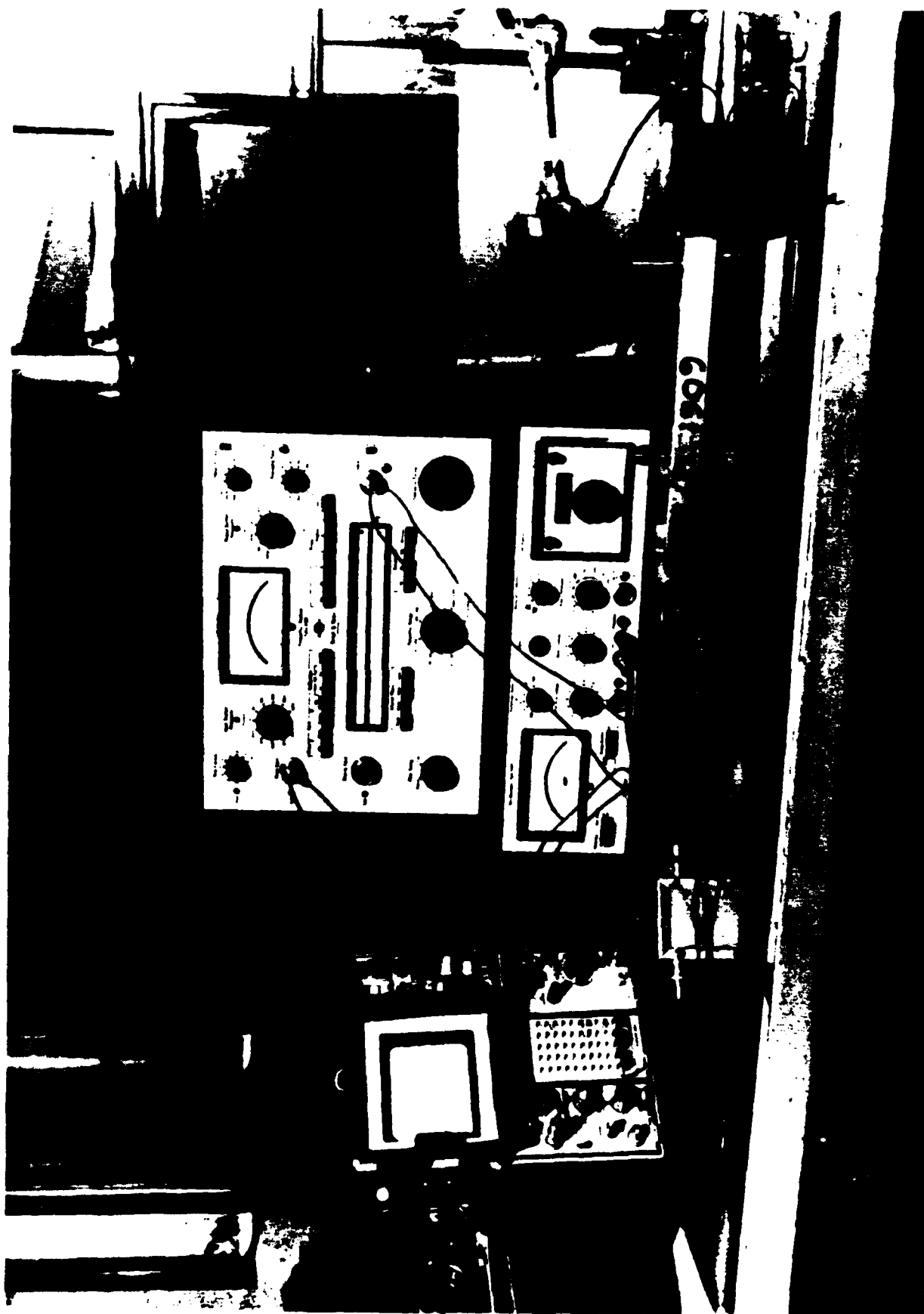
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FIGURE 6 IFD-NDE EXPERIMENTAL SETUP

8409-2

center of the picture is a sine generator which is used to drive the shaker. The device at top center is a frequency analyzer which receives the decay signal from the accelerometer, filters the signal, and amplifies the signal. The device to the left is a storage oscilloscope which displays the decay signal after it has been filtered and amplified by the frequency analyzer.

The small box below the oscilloscope is a triggering device which simultaneously cuts off the signal to the shaker and activates the oscilloscope to record the decay signal.

A photograph is taken of the decay trace on the oscilloscope screen and this is used as the raw data. A typical picture of the decay trace is seen in Figure 7.

Data taken from the photograph along with the driving frequency and oscilloscope sweep time is reduced to a specific damping capacity by use of the formula:

$$\frac{\Delta W}{W} = 1 - e^{-2\alpha}$$

where: $\frac{\Delta W}{W}$ = specific damping capacity

$$\alpha = \frac{1}{N} \ln \frac{A_o}{A_n}$$

where: N = Number of cycles between any two points on the decay trace

A_o = Relative amplitude of signal at 0 cycles

A_n = Relative amplitude of signal at N cycles
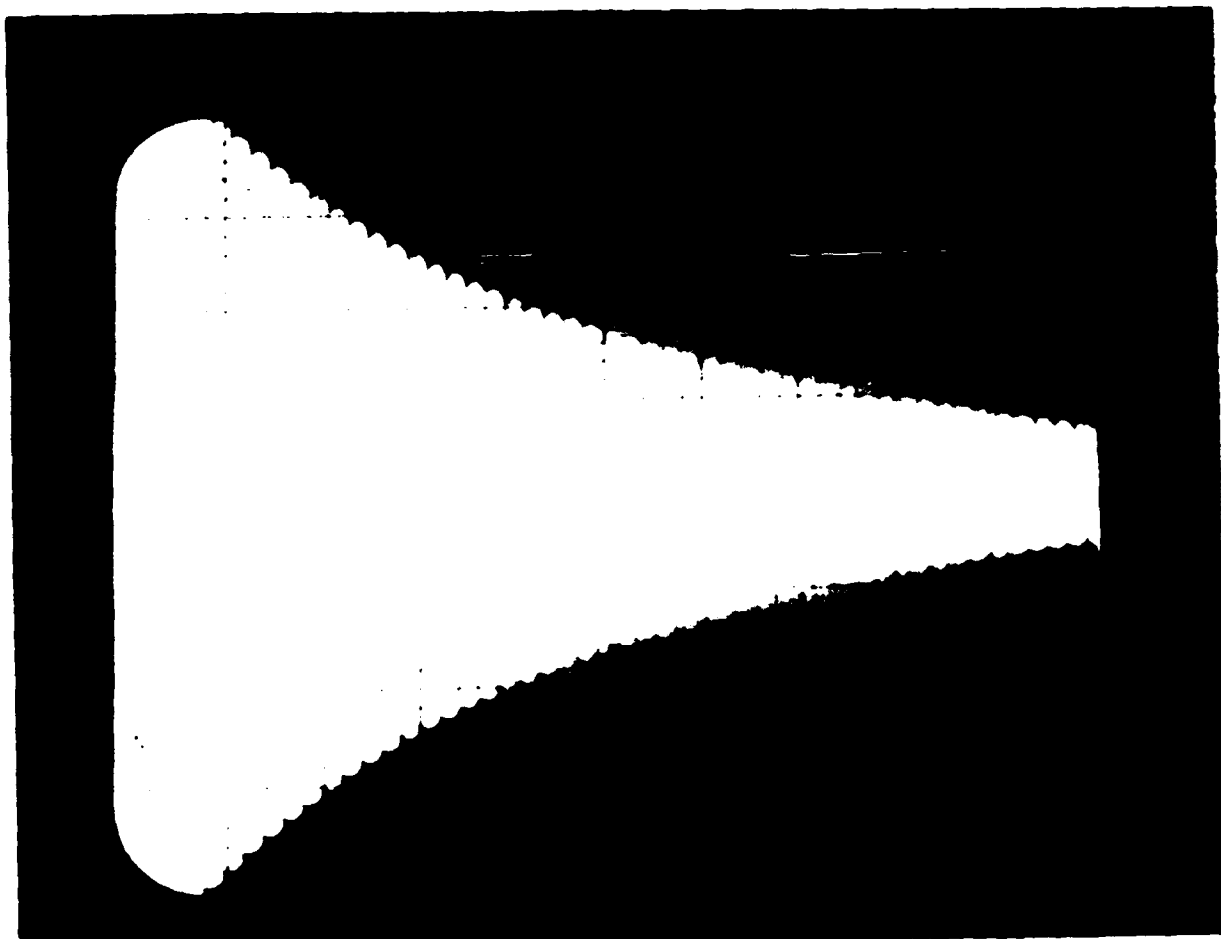
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FIGURE 7 PHOTOGRAPH OF TYPICAL DECAY TRACE AS SEEN ON
STORAGE OSCILLOSCOPE

8409-3

The data collected during the program is displayed in Figures 8A through 15B.

In these figures, those data series which had five pickup positions (i.e. Figure XA through XE) has a stress raiser notch present. The stress raiser notch has a radius of 0.25" and a depth of 0.030". In these figures, data position no. 2 is on the center of the compression side of the specimen. Data positions no. 1 and no. 3 are two inches either side of position no. 2. Data positions no. 4 and no. 5 are either side of the stress raiser notch which is on the tension side of the specimen.

Those data series which had four pickup positions (i.e. Figures XA through XD) had no stress raiser notch. In these figures, data positions 1 through 3 were also as described above. Data position no. 4 was on the center of the tension side of the specimen.

For figure series 14 and 15, only two data points were collected, those being on the center of the compression and tension faces respectively. (Pickup locations 1 and 4.)

Stress raiser notches were employed in order to ascertain whether a difference existed in the data when the failure mechanism was more concentrated.
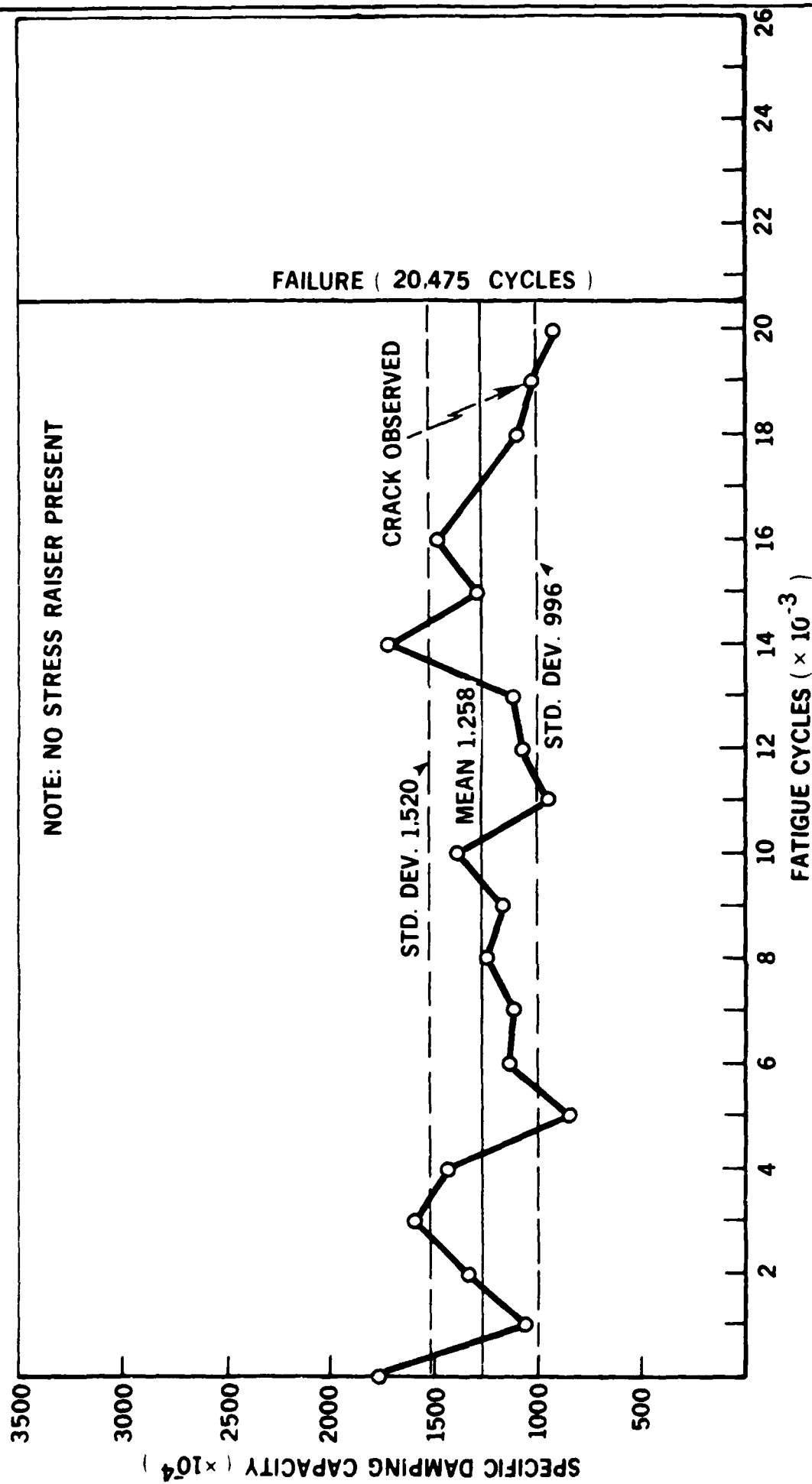
FIGURE 8A MATERIAL: 7075 AL, SPECIMEN NO: 1, PICKUP POSITION: 1

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8409-27

FIGURE 8B MATERIAL: 7075 AL, SPECIMEN NO: 1, PICKUP POSITION: 2

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8409-28

FIGURE 8C MATERIAL: 7075 AL, SPECIMEN NO: 1, PICKUP POSITION: 3

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NOTE: NO STRESS RAISER PRESENT

FAILURE (20,475 CYCLES)

MEAN 1,233

STD. DEV. 1,431

STD. DEV. 1,035

CRACK OBSERVED

SPECIFIC DAMPING CAPACITY (×10⁴)

FATIGUE CYCLES (× 10³)
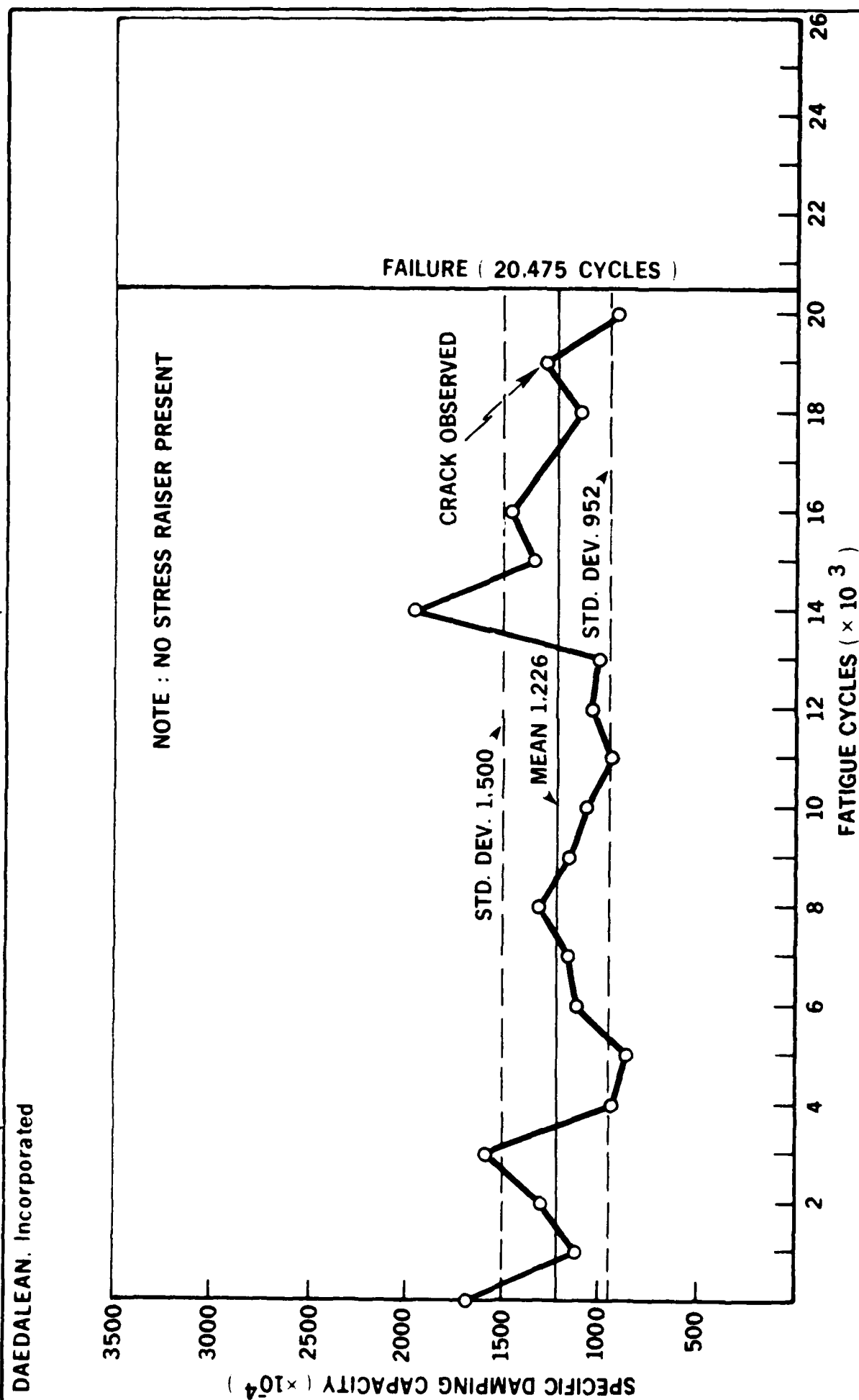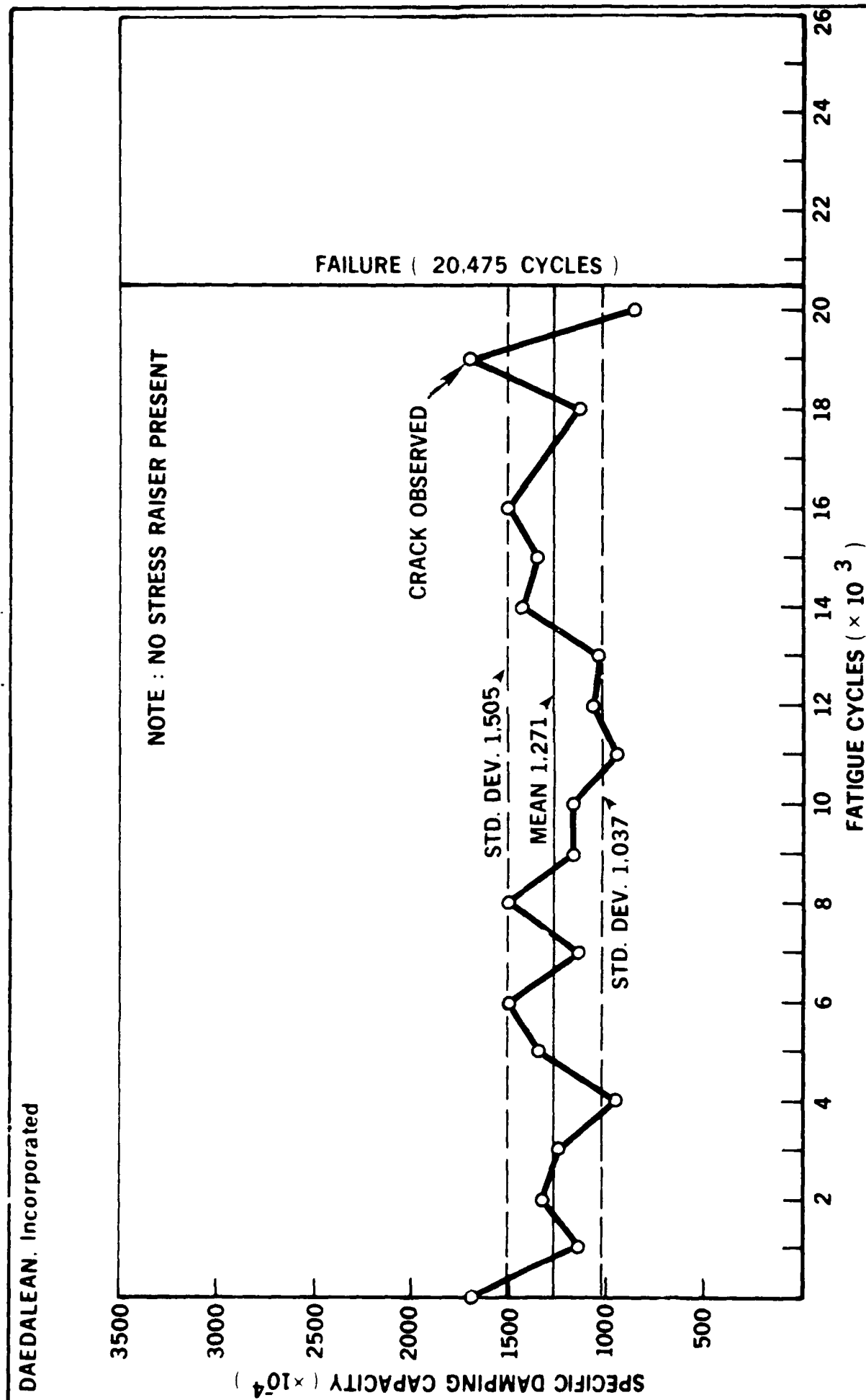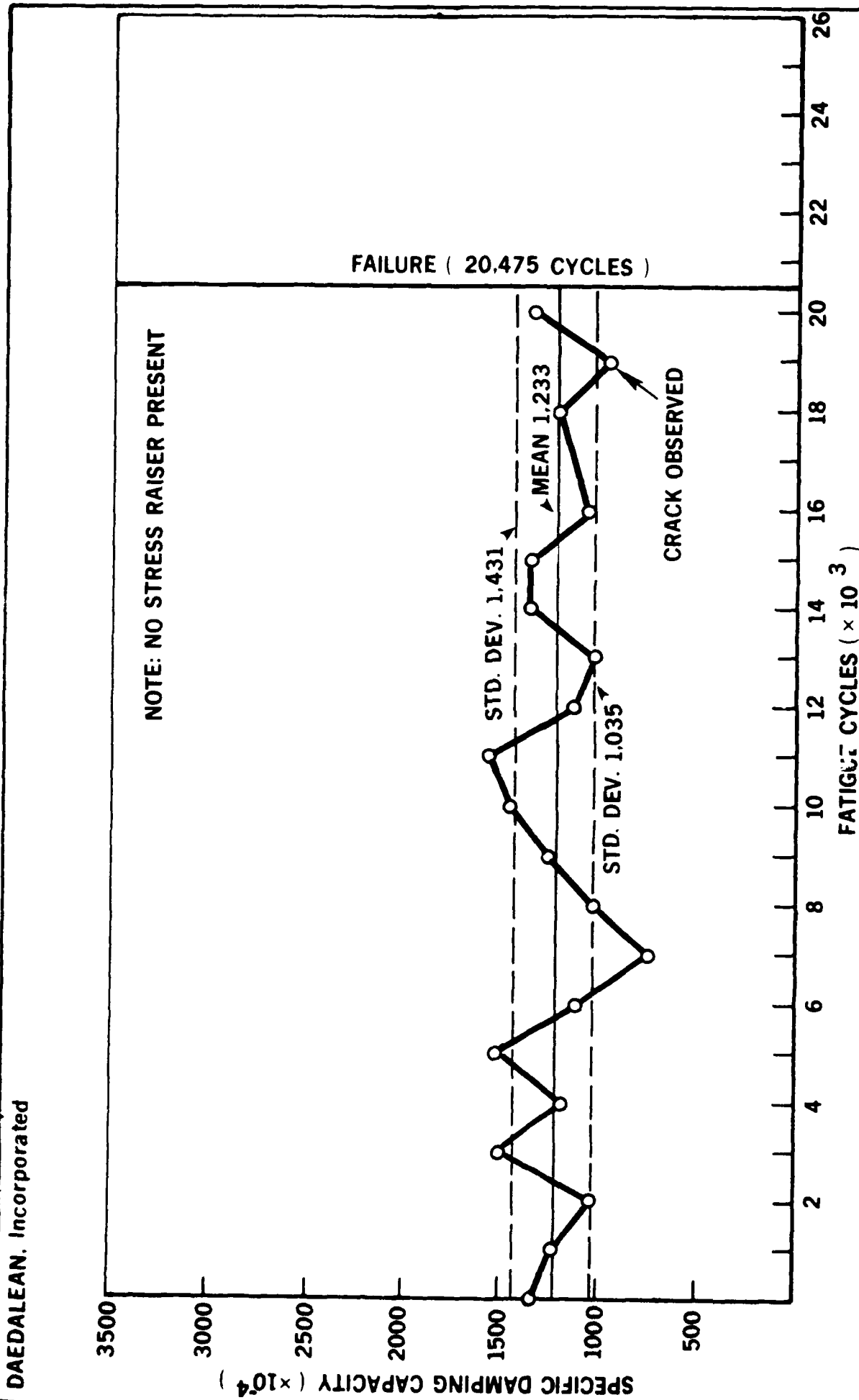
FIGURE 8D MATERIAL: 7075 AL. SPECIMEN NO: 1, PICKUP POSITION: 4

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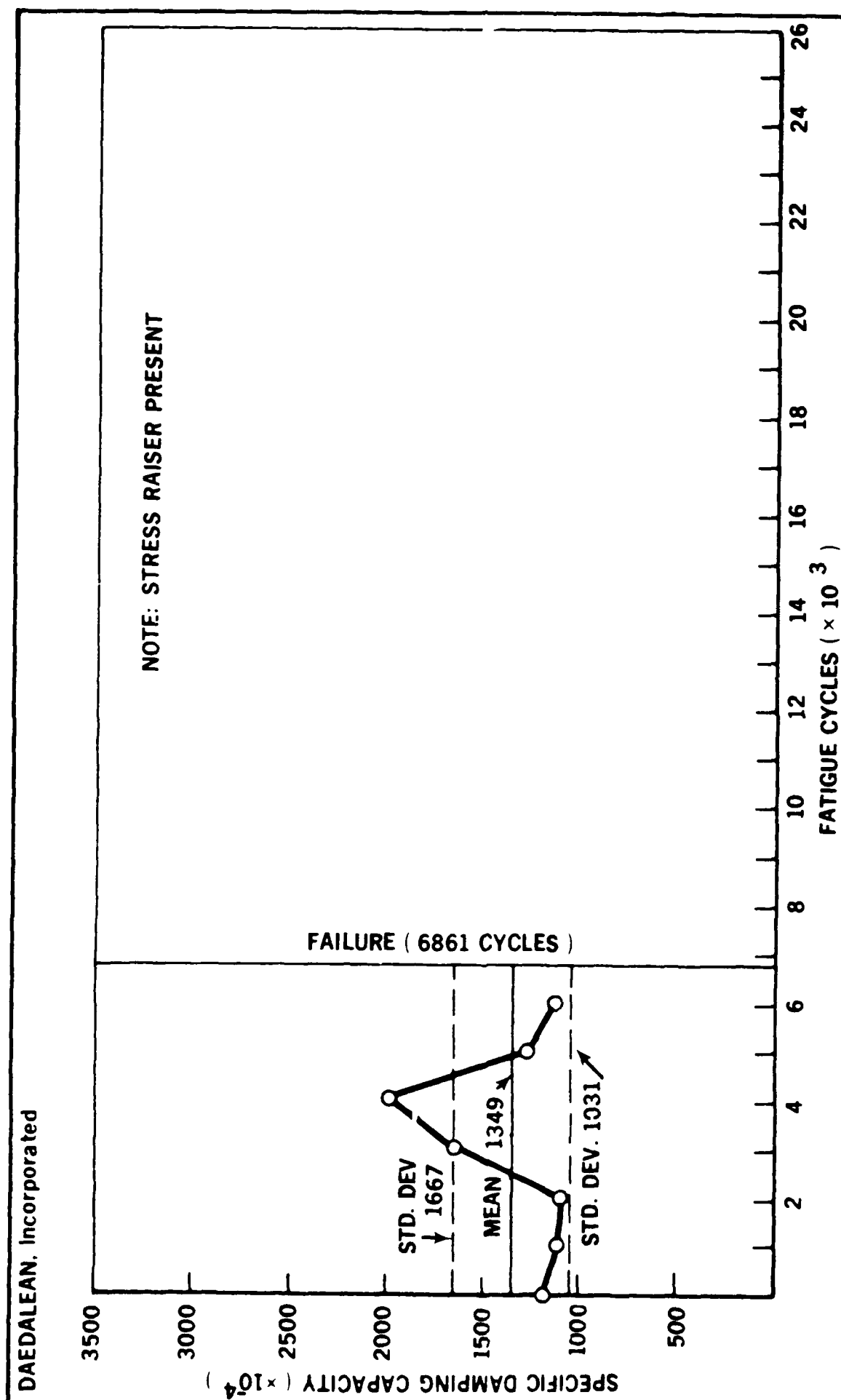
FIGURE 9A MATERIAL: 7075 , SPECIMEN NO: 2, PICKUP POSITION: 1

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8409-31

FIGURE 9B MATERIAL: 7075 , SPECIMEN NO: 2, PICKUP POSITION: 2

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8409-32

NOTE : STRESS RAISER PRESENT
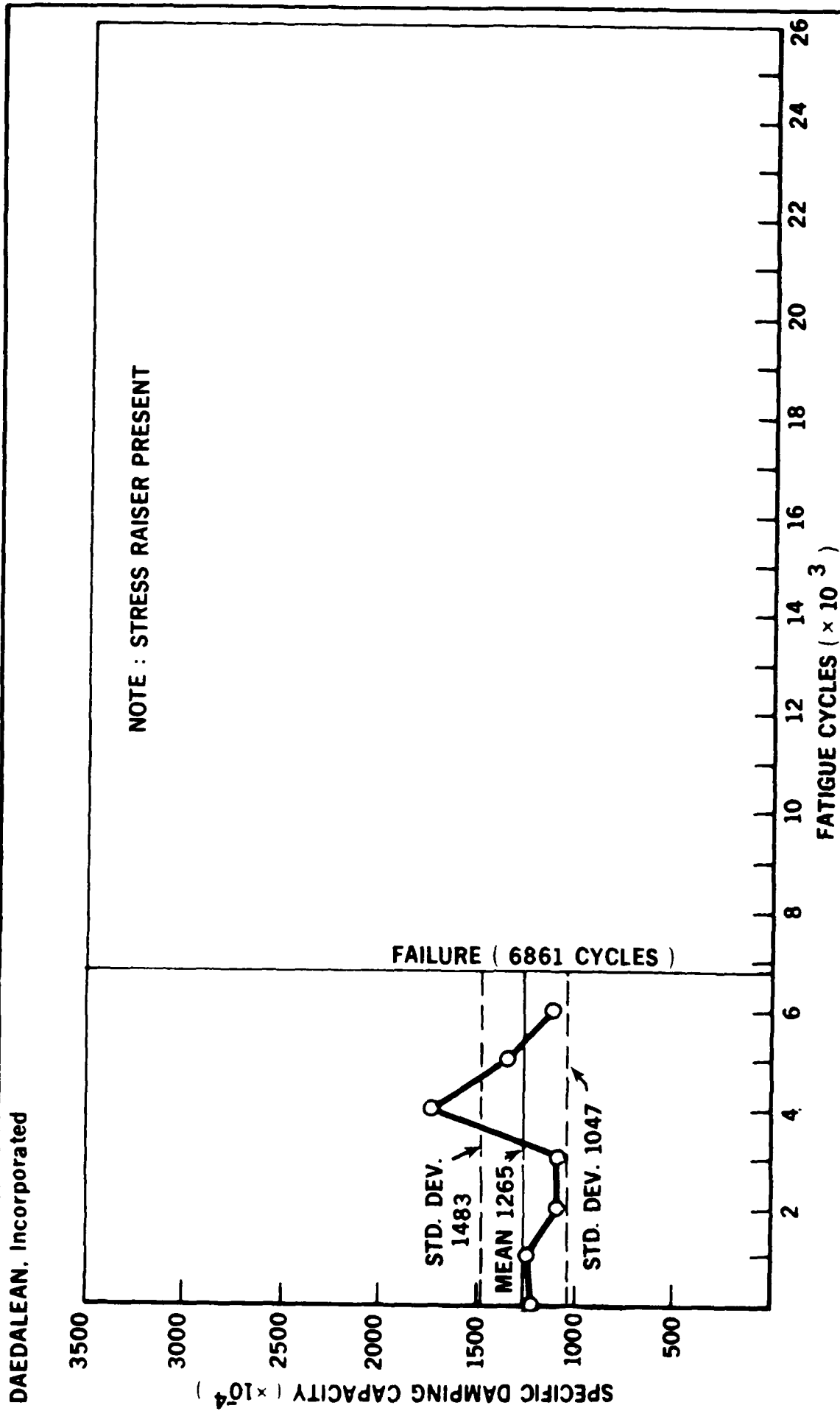
FIGURE 9C MATERIAL: 7075 , SPECIMEN NO: 2, PICKUP POSITION: 3

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8409-33

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NOTE: STRESS RAISER PRESENT

FAILURE (6861 CYCLES)

STD. DEV. 1476

MEAN 1251

STD. DEV. 1026

SPECIFIC DAMPING CAPACITY (×10⁴)

FATIGUE CYCLES (× 10³)
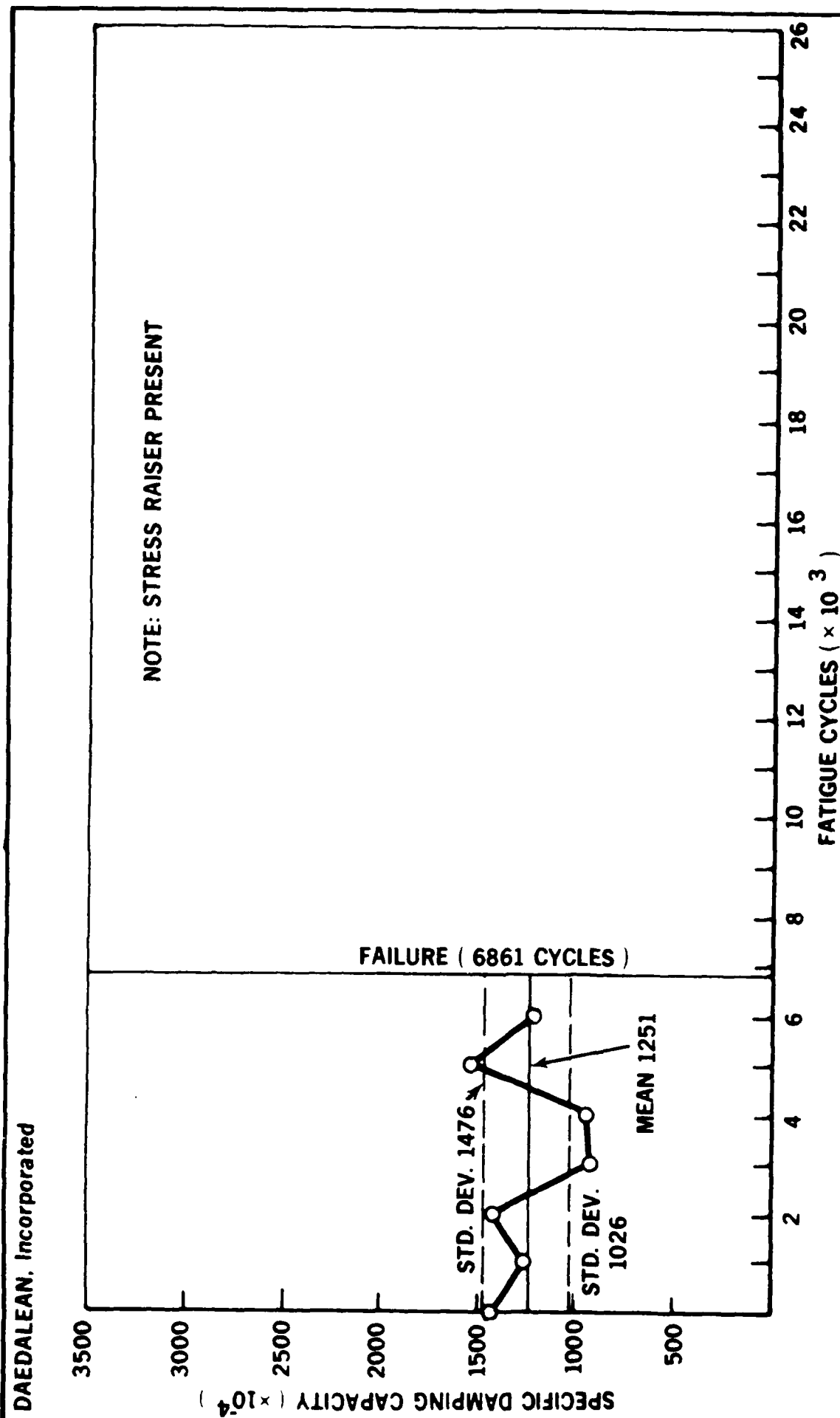
FIGURE 9D MATERIAL: 7075 , SPECIMEN NO: 2, PICKUP POSITION: 4

8409-34

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NOTE : STRESS RAISER PRESENT

FAILURE (6861 CYCLES)

STD. DEV. 1572

MEAN 1278

STD. DEV. 984

SPECIFIC DAMPING CAPACITY (×10⁻⁴)

FATIGUE CYCLES (× 10³)

FIGURE 9E MATERIAL: 7075 , SPECIMEN NO: 2, PICKUP POSITION: 5

8409-35
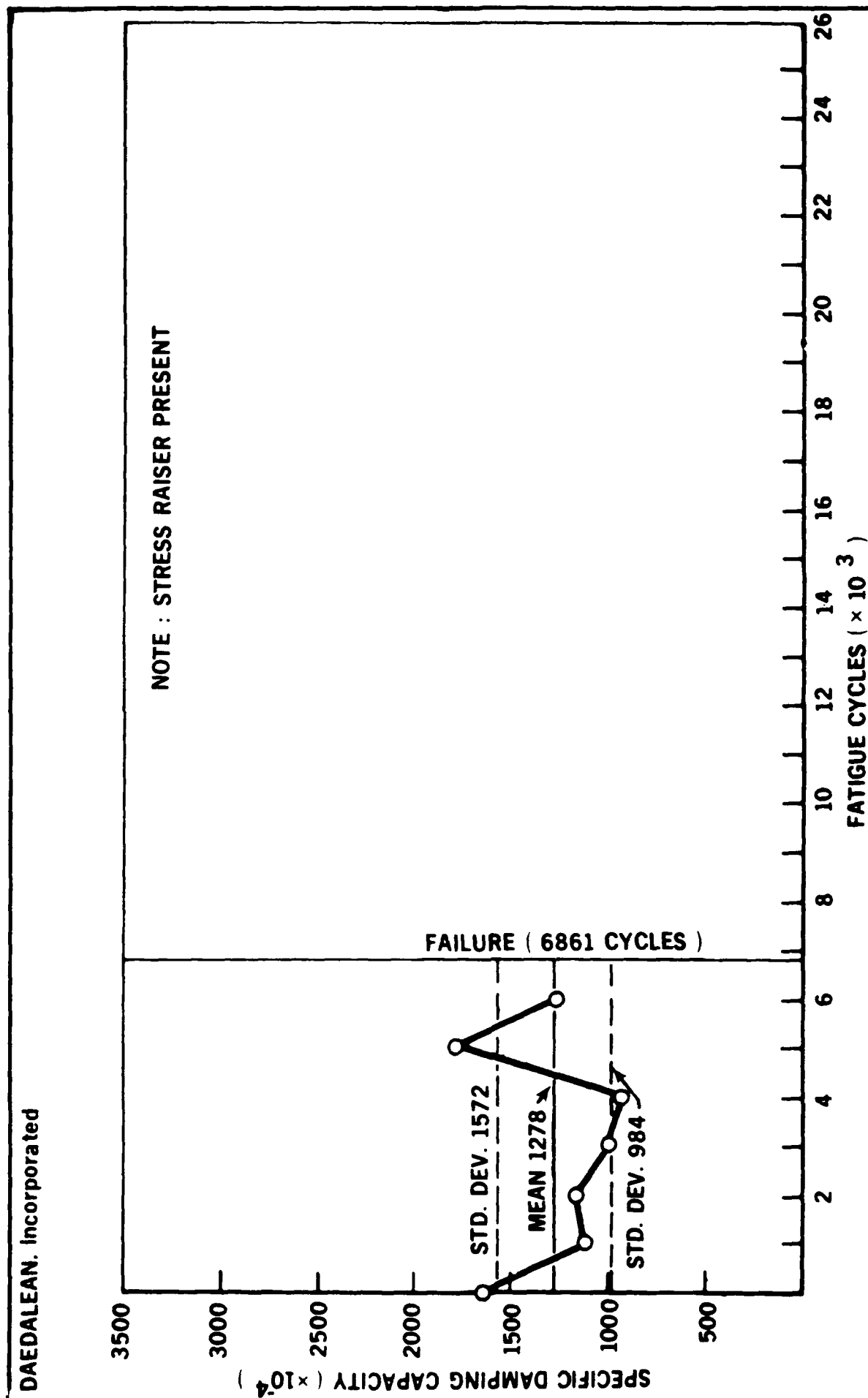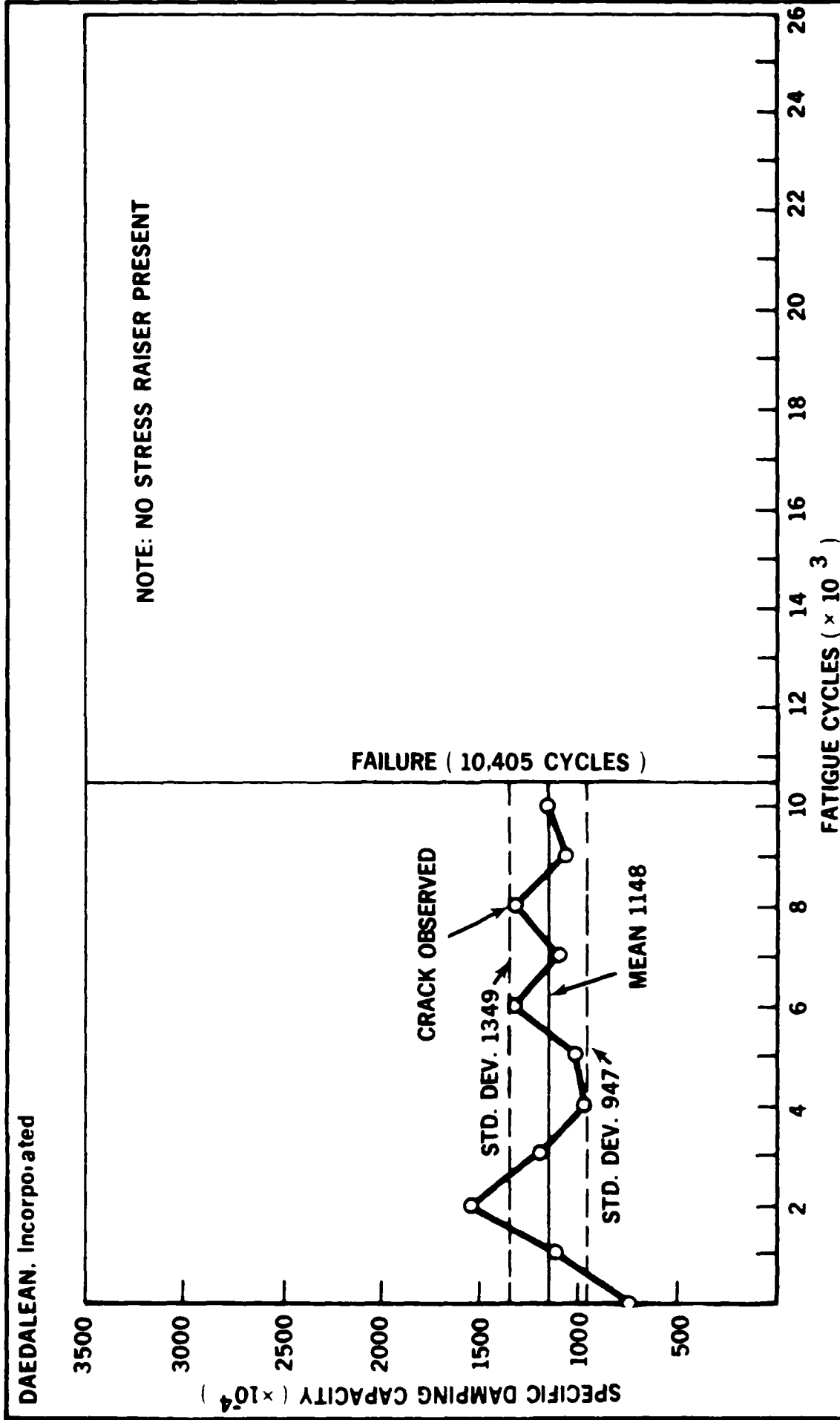
FIGURE 10A MATERIAL: 7075 , SPECIMEN NO: 3, PICKUP POSITION: 1

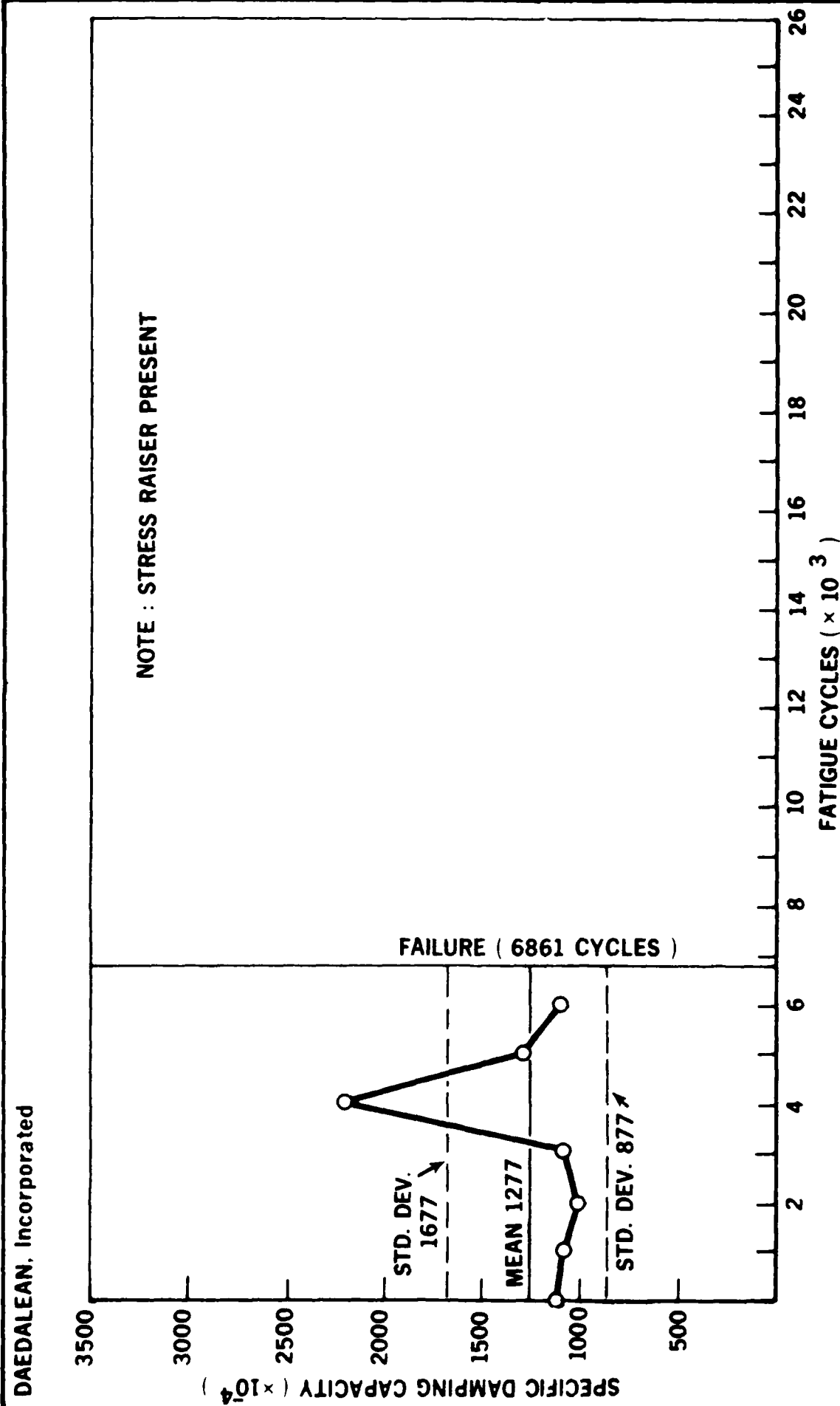8409-36
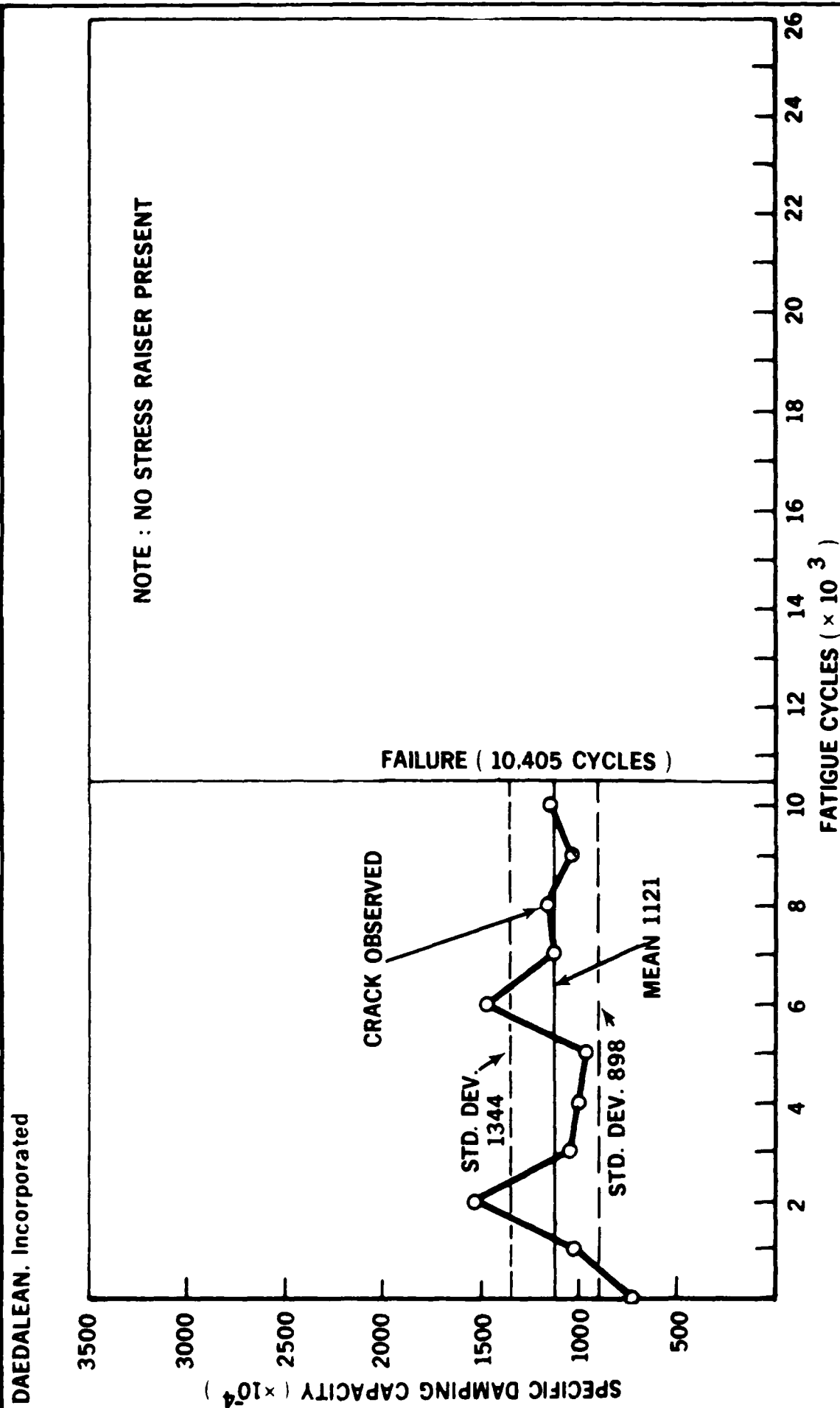
FIGURE 10B MATERIAL: 7075, SPECIMEN NO: 3, PICKUP POSITION: 2

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8409-37
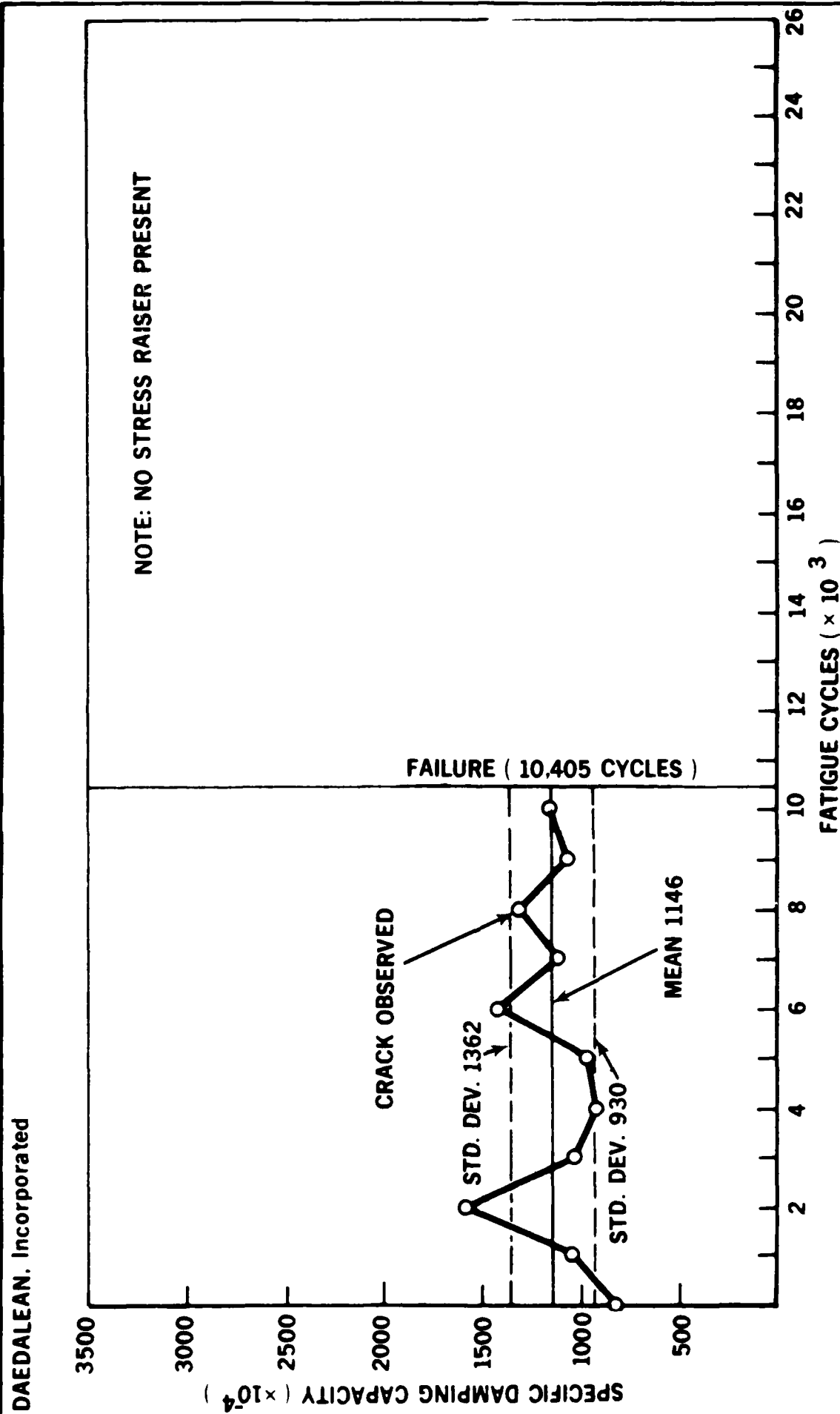
FIGURE 10C MATERIAL: 7075 , SPECIMEN NO: 3, PICKUP POSITION: 3

NOTE: NO STRESS RAISER PRESENT

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8409-38

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NOTE : NO STRESS RAISER PRESENT

FAILURE (10,405 CYCLES)

CRACK OBSERVED

STD. DEV. 1579

MEAN 1292

STD. DEV. 1005

FATIGUE CYCLES (× 10³)

SPECIFIC DAMPING CAPACITY (×10⁴)

FIGURE 10D MATERIAL: 7075 , SPECIMEN NO: 3, PICKUP POSITION: 4

8409-39

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NOTE: NO STRESS RAISER PRESENT

FAILURE (9.886 CYCLES)

STD. DEV. 1.763

MEAN 1.348

STD. DEV. 933

SPECIFIC DAMPING CAPACITY (×10⁴)

FATIGUE CYCLES (× 10³)

FIGURE 11A MATERIAL: 6061 AL, SPECIMEN NO: 1, PICKUP POSITION: 1

8409-40

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NOTE: NO STRESS RAISER PRESENT

FAILURE (9.886 CYCLES)

STD. DEV. 1.763

MEAN 1.318

STD. DEV. 873

SPECIFIC DAMPING CAPACITY (×10⁴)

FATIGUE CYCLES (× 10³)

FIGURE 11B MATERIAL: 6061 AL, SPECIMEN NO: 1, PICKUP POSITION: 2

8409-41

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FIGURE 11C MATERIAL: 6061 AL, SPECIMEN NO: 1, PICKUP POSITION: 3

8409-42

NOTE : NO STRESS RAISER PRESENT

FAILURE (9.886 CYCLES)

STD. DEV. 2.355

MEAN 1.644

STD. DEV. 933

FATIGUE CYCLES (× 10³)

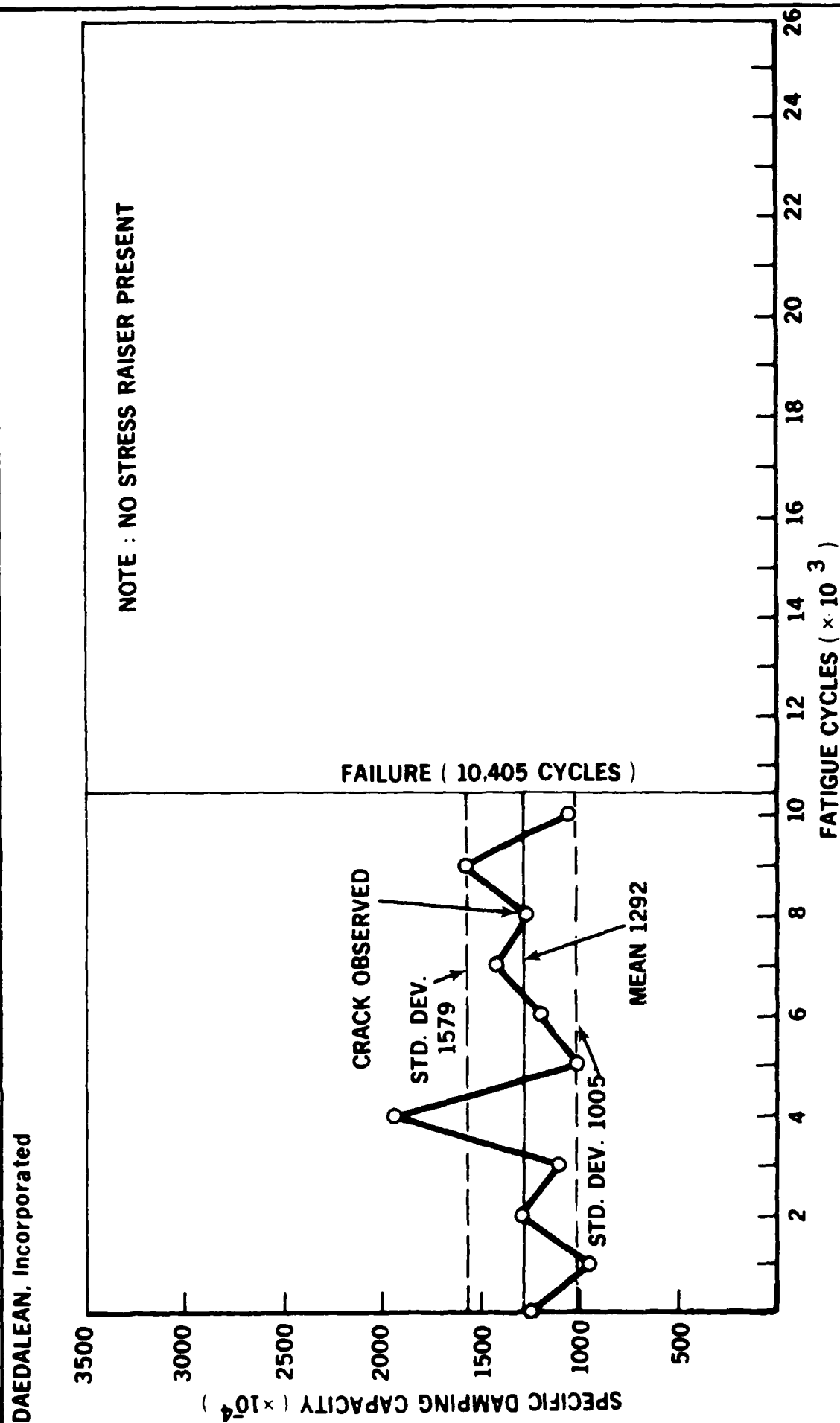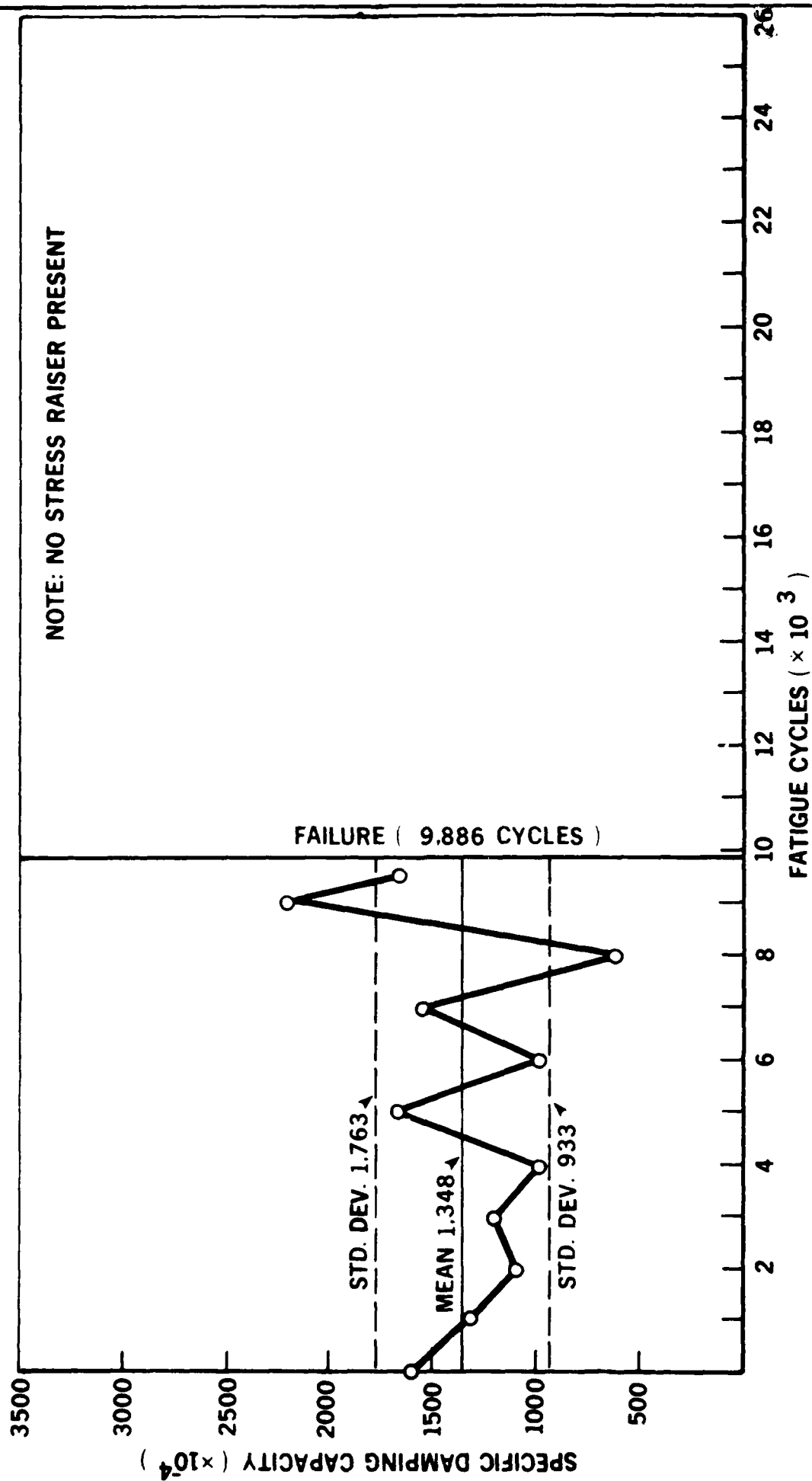SPECIFIC DAMPING CAPACITY (× 10⁴)

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FIGURE 11D MATERIAL: 6061 AL. SPECIMEN NO: 1, PICKUP POSTION: 4

8409-43

FIGURE 12A MATERIAL: 6061 AL, SPECIMEN NO: 2, PICKUP POSITION: 1

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8409-44

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NOTE: STRESS RAISER PRESENT

FAILURE (18,286 CYCLES)

STD. DEV. 1,642 ◄

MEAN 1.223 ◄

STD. DEV. 804 ◄

CRACK OBSERVED

SPECIFIC DAMPING CAPACITY ($\times 10^{-4}$)

FATIGUE CYCLES ($\times 10^3$)

3500
3000
2500
2000
1500
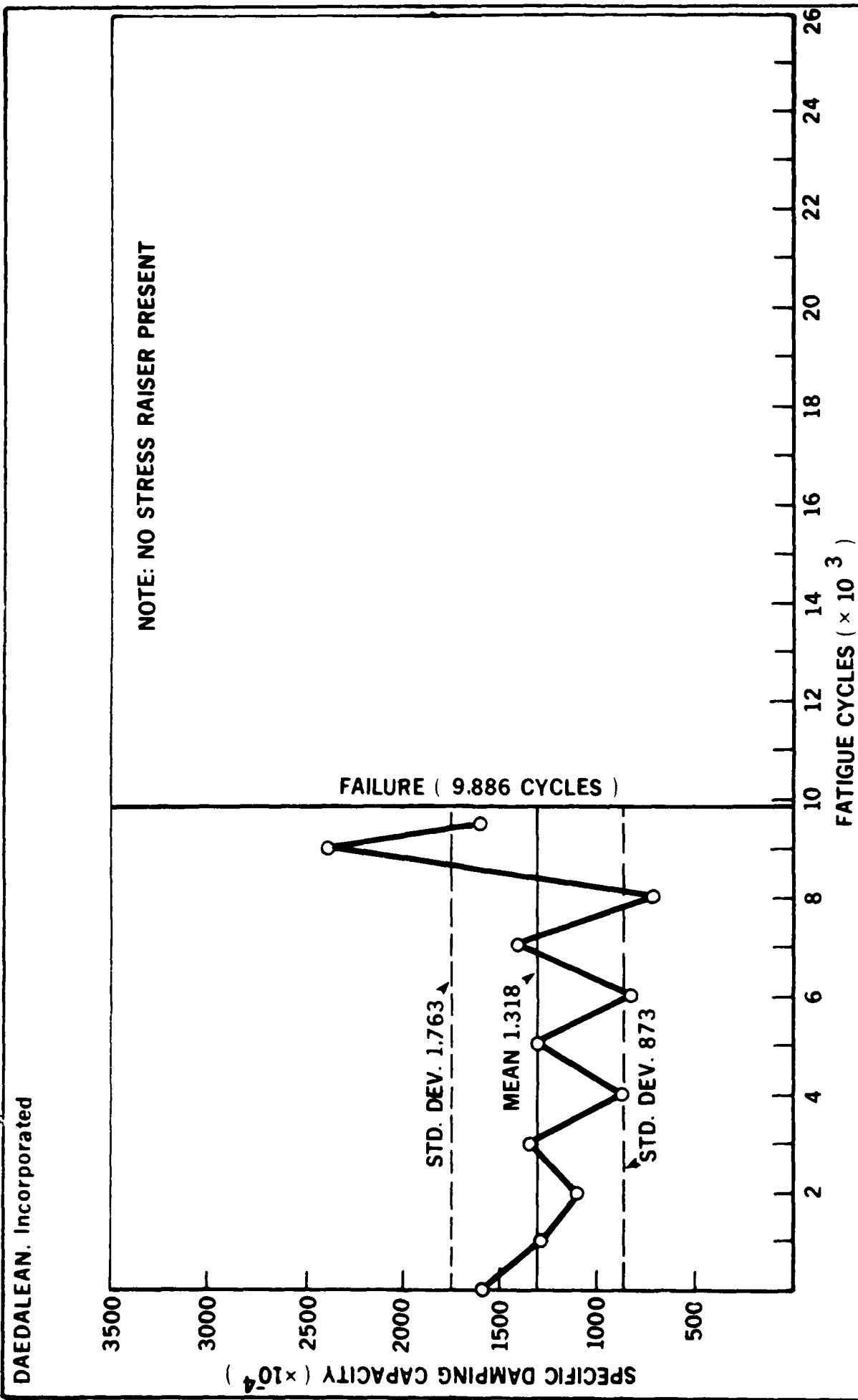1000
500

2 4 6 8 10 12 14 16 18 20 22 24 26

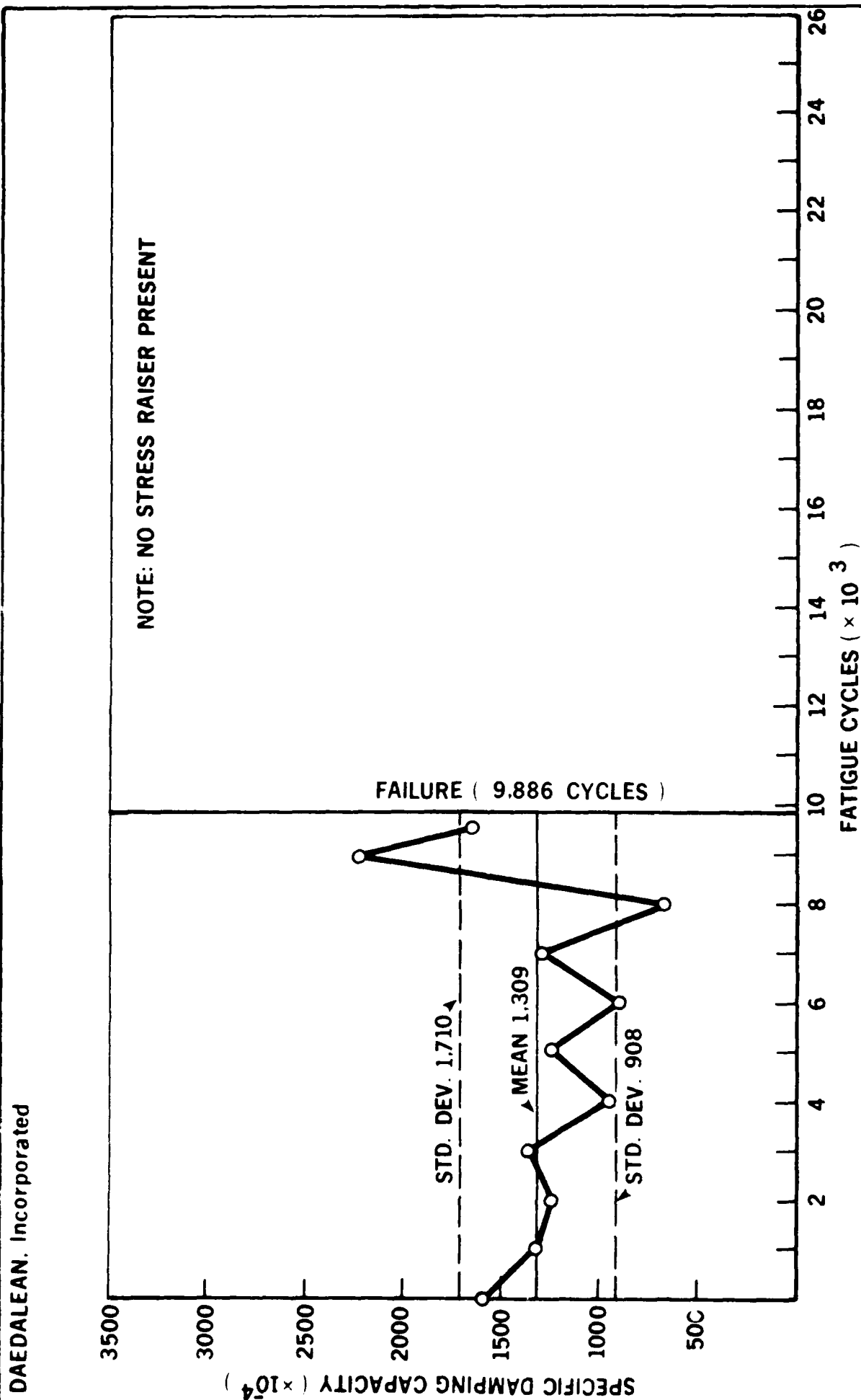FIGURE 12B MATERIAL: 6061 AL, SPECIMEN NO: 2, PICKUP POSITION: 2

FIGURE 12C MATERIAL: 6061 AL, SPECIMEN NO: 2, PICKUP POSITION: 3
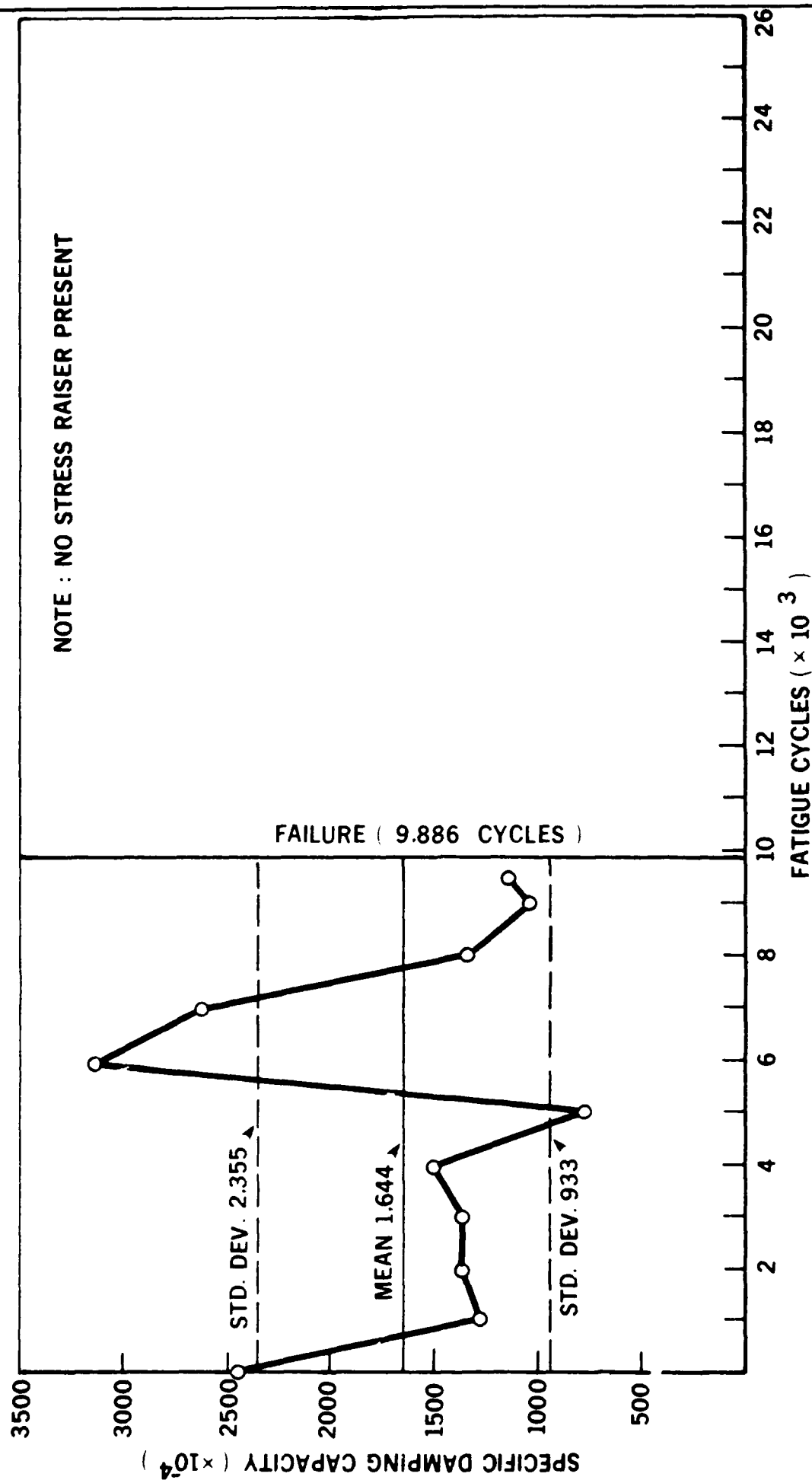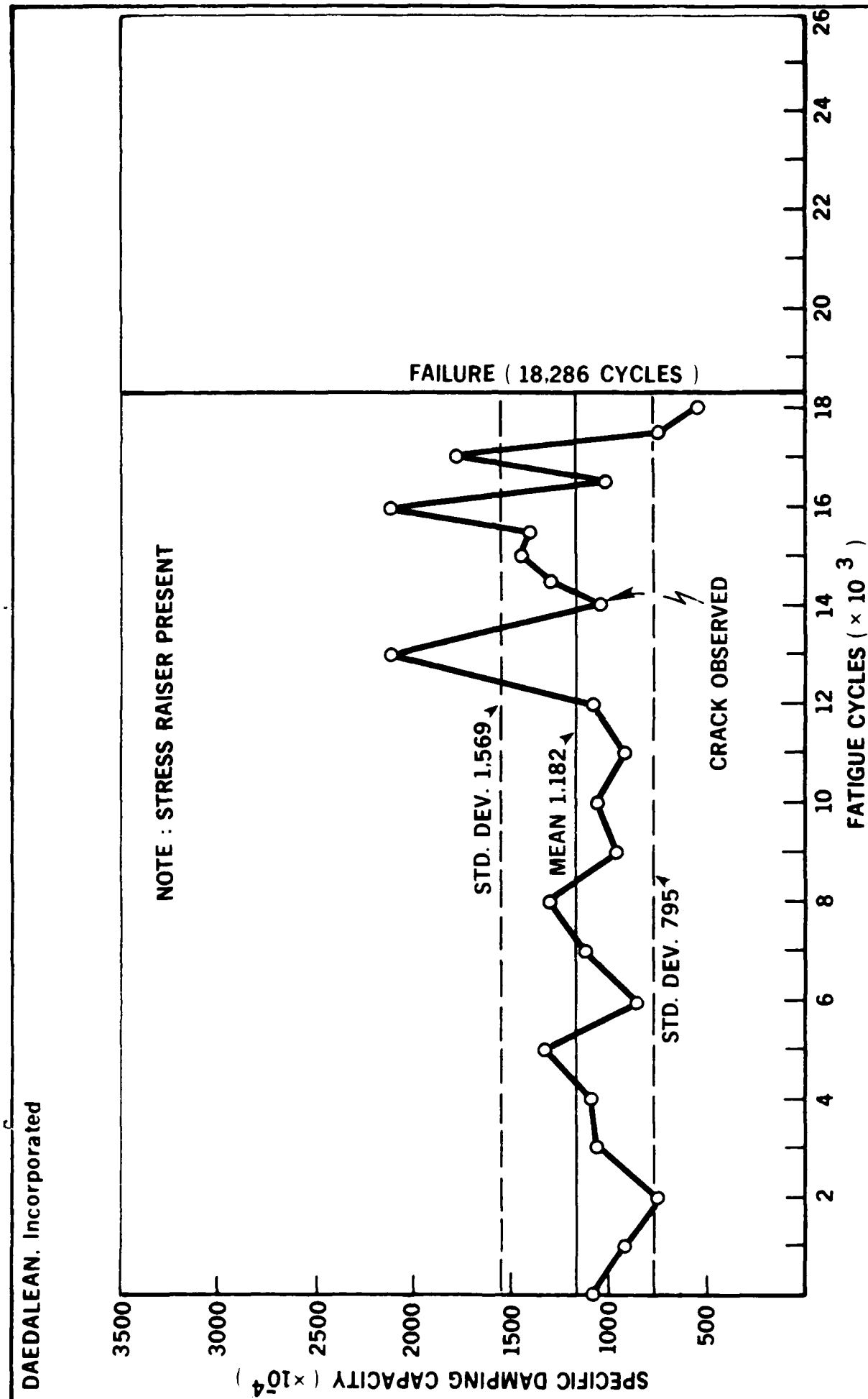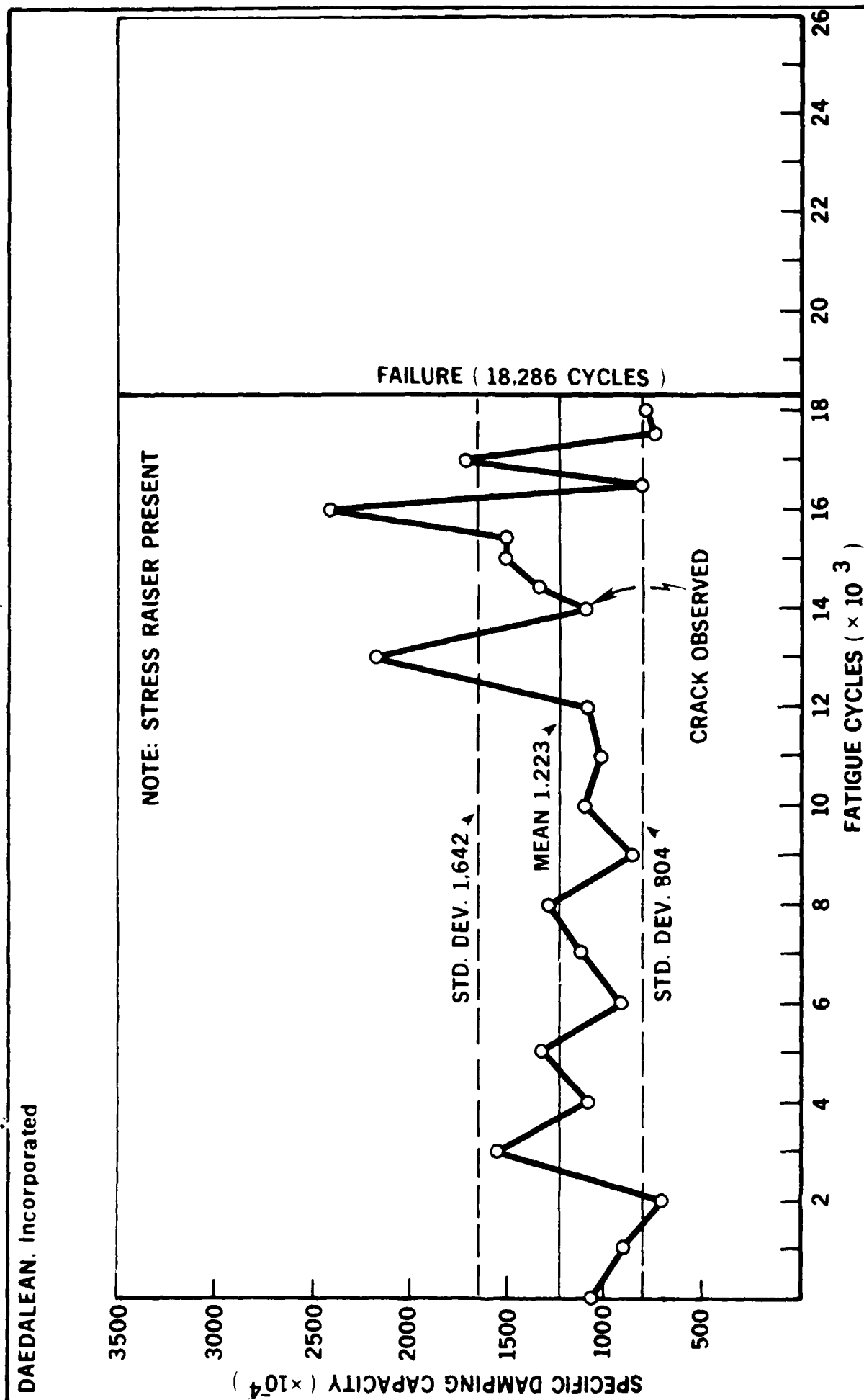
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FIGURE 12D MATERIAL: 6061 AL. SPECIMEN NO: 2, PICKUP POSITION: 4

NOTE: STRESS RAISER PRESENT

FAILURE (18.286 CYCLES)

CRACK OBSERVED

STD. DEV. 1.695

MEAN 1.361

STD. DEV. 1.027

SPECIFIC DAMPING CAPACITY (×10⁴)

FATIGUE CYCLES (× 10³)

8409.47

FIGURE 12E MATERIAL: 6061 AL, SPECIMEN NO: 2, PICKUP POSITION: 5

8409-48

FIGURE 13A MATERIAL: 6061 , SPECIMEN NO: 3, PICKUP POSITION: 1

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8409-30

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NOTE: NO STRESS RAISER NOTCH PRESENT

FAILURE (8,741 CYCLES)

STD. DEV. 2101

MEAN 1553

STD. DEV. 1005

SPECIFIC DAMPING CAPACITY ($\times 10^4$)

FATIGUE CYCLES ($\times 10^3$)

FIGURE 13B MATERIAL: 6061 . SPECIMEN NO: 3, PICKUP POSITION: 2

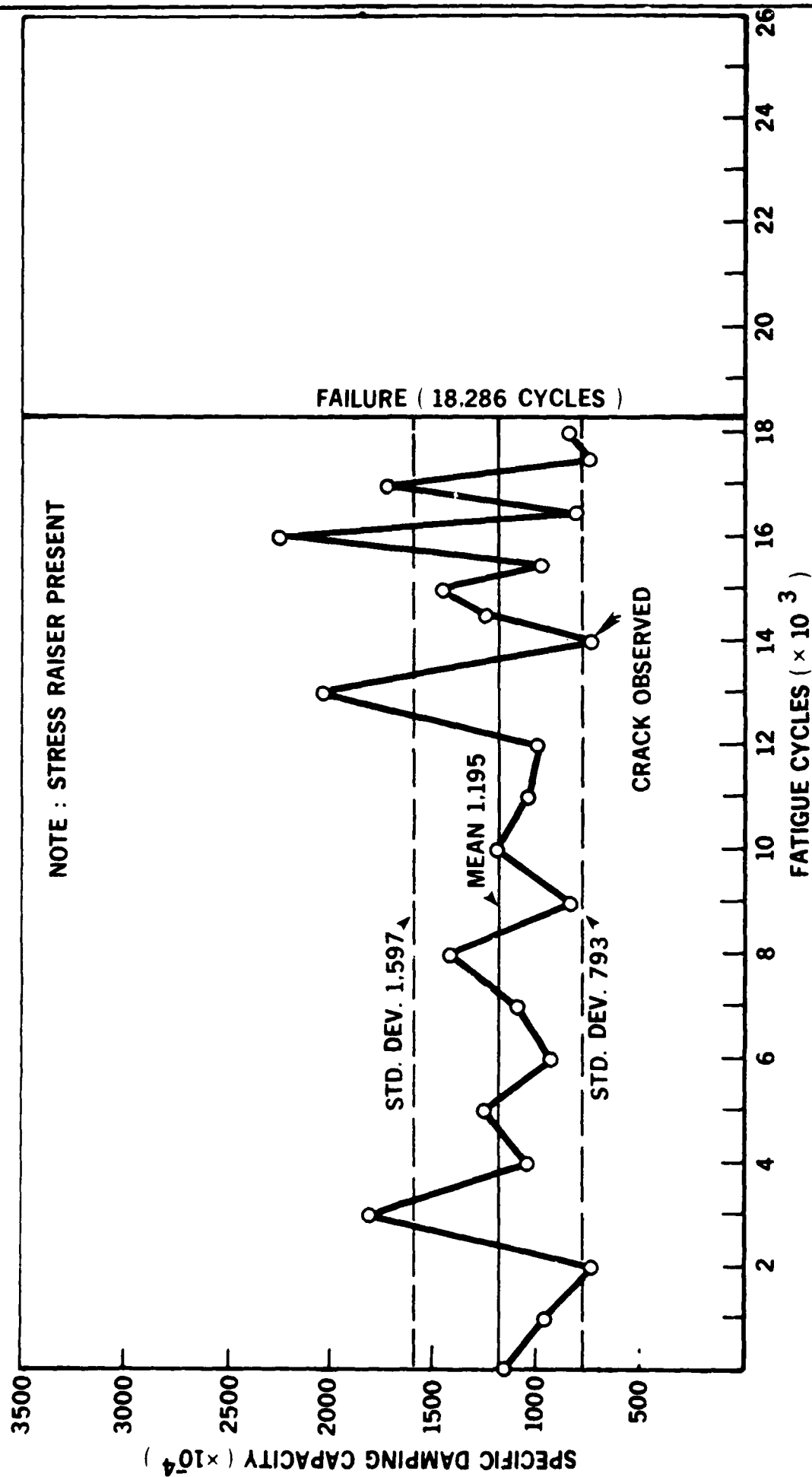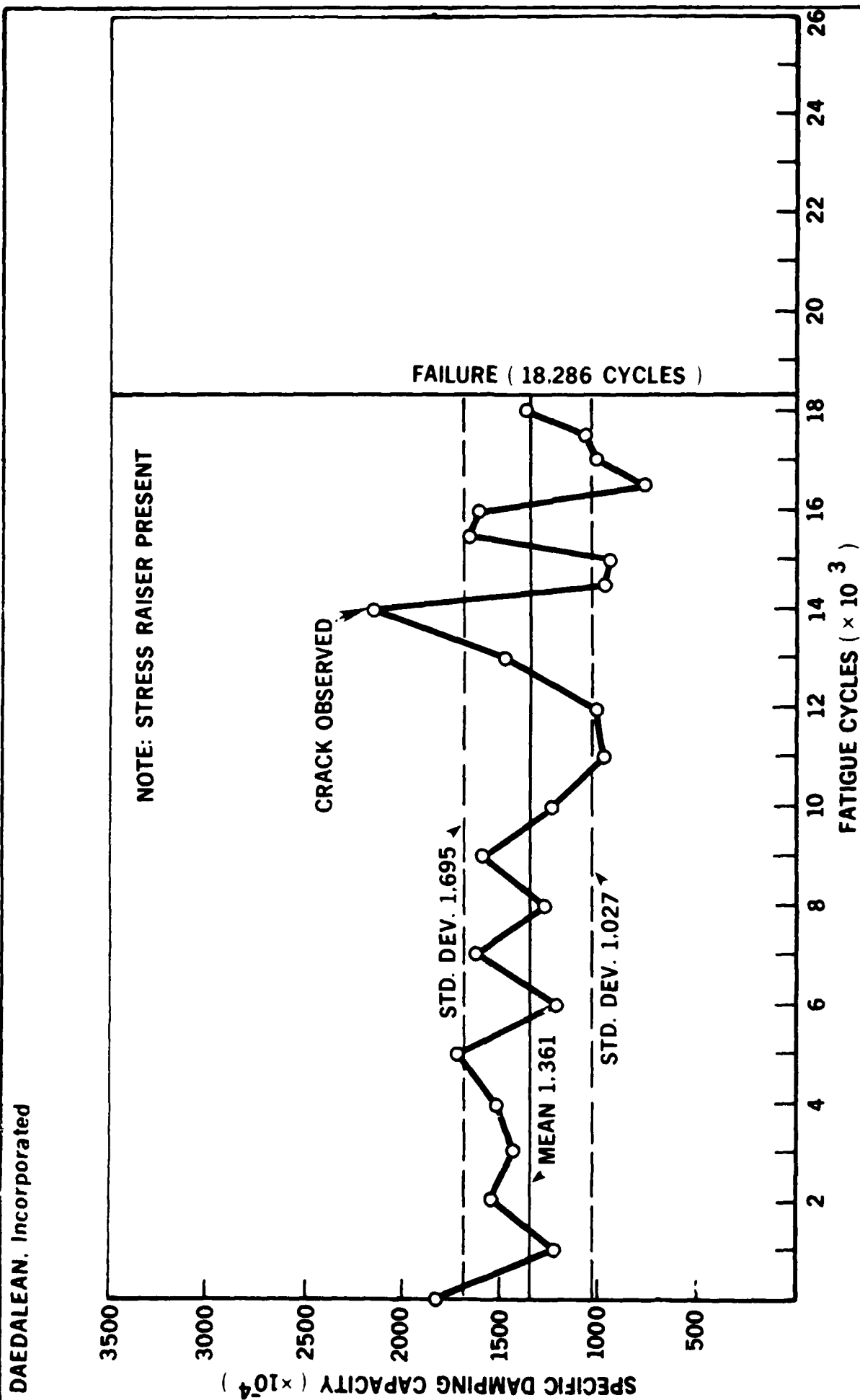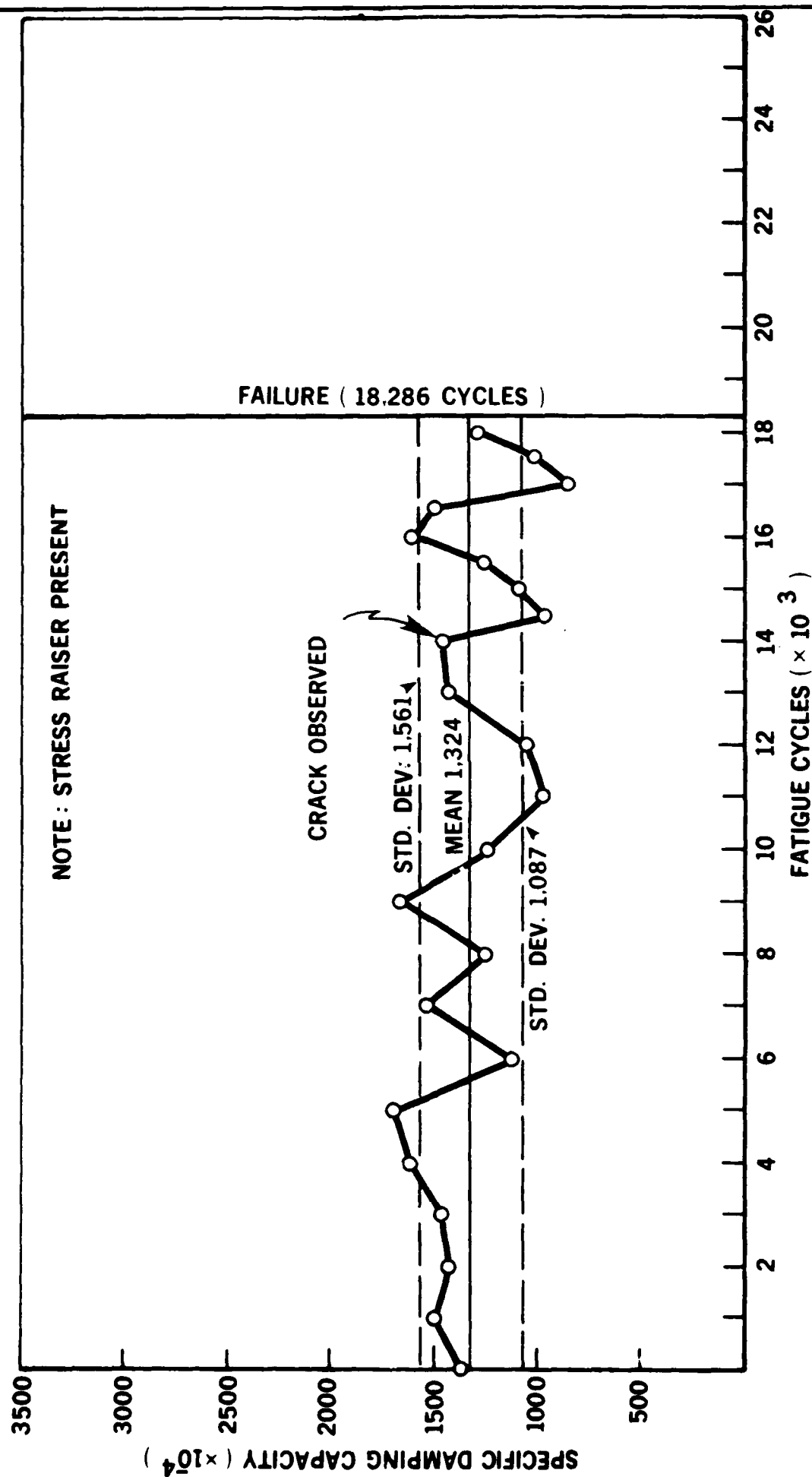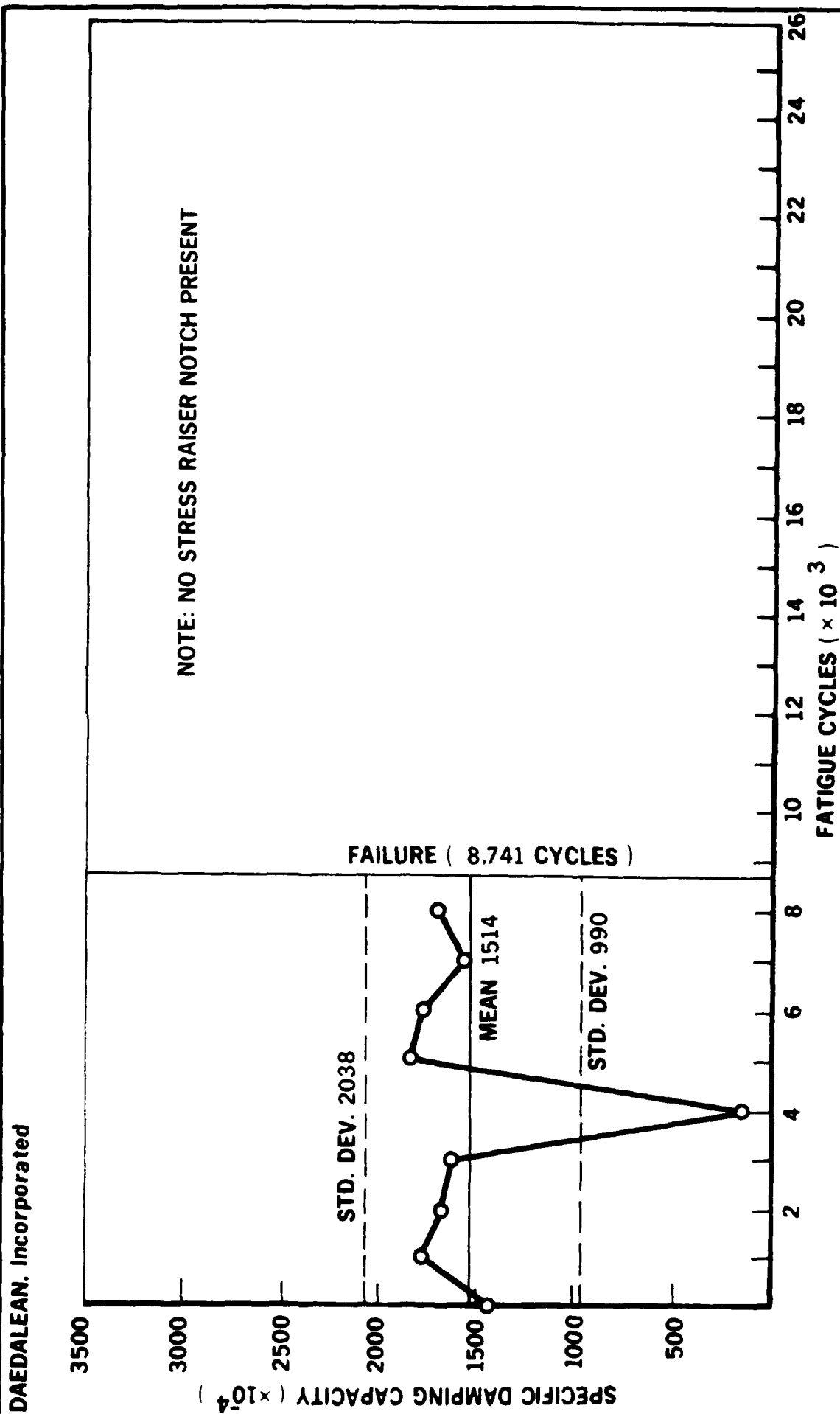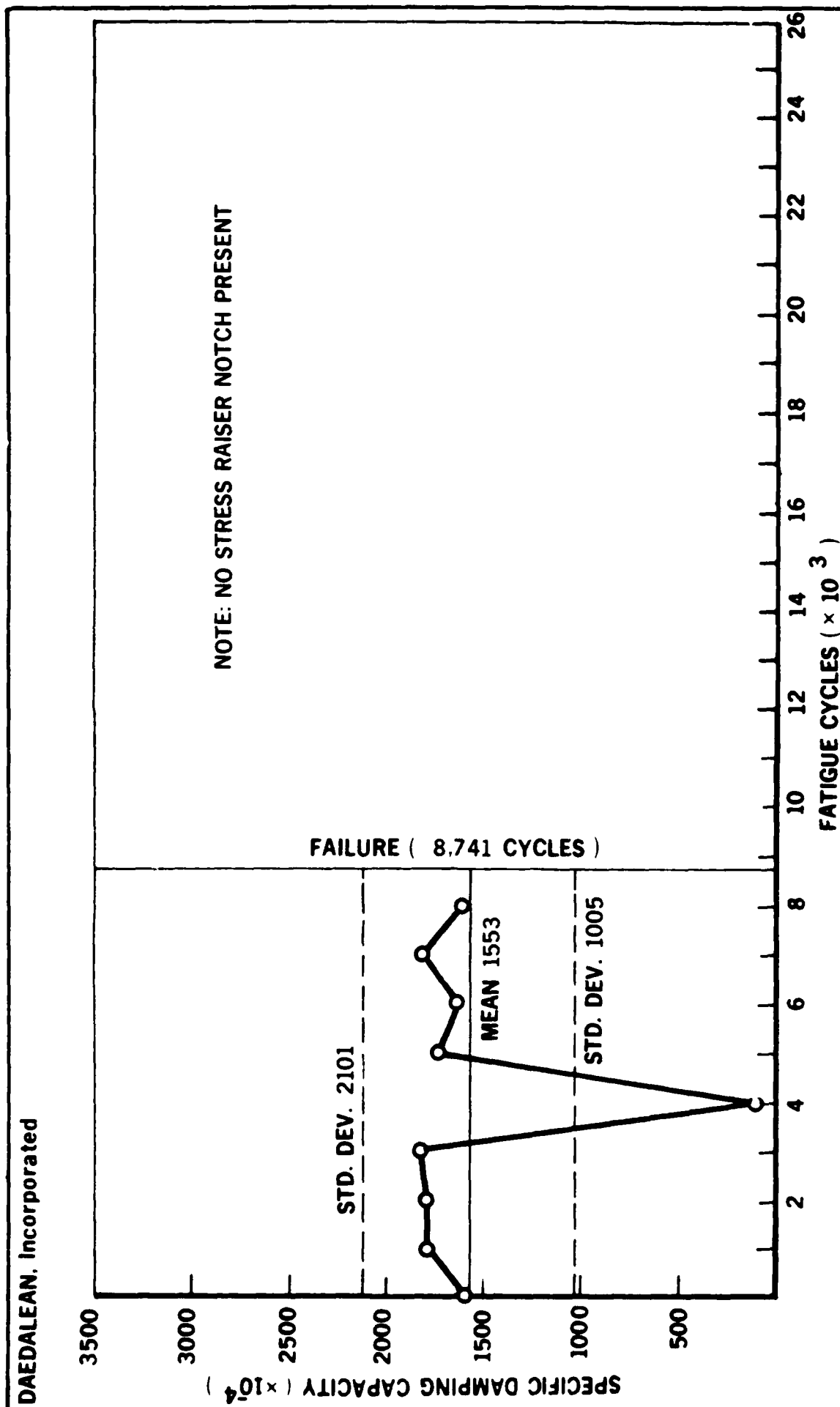FIGURE 13C MATERIAL: 6061 , SPECIMEN NO: 3, PICKUP POSITION:3

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8409-32

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NOTE: NO STRESS RAISER NOTCH PRESENT

FAILURE (8.741 CYCLES)

MEAN 1692

STD. DEV. 1860

STD. DEV. 1524

SPECIFIC DAMPING CAPACITY (×10⁴)

3500 3000 2500 2000 1500 1000 500

FATIGUE CYCLES (× 10³)

2   4   6   8   10   12   14   16   18   20   22   24   26
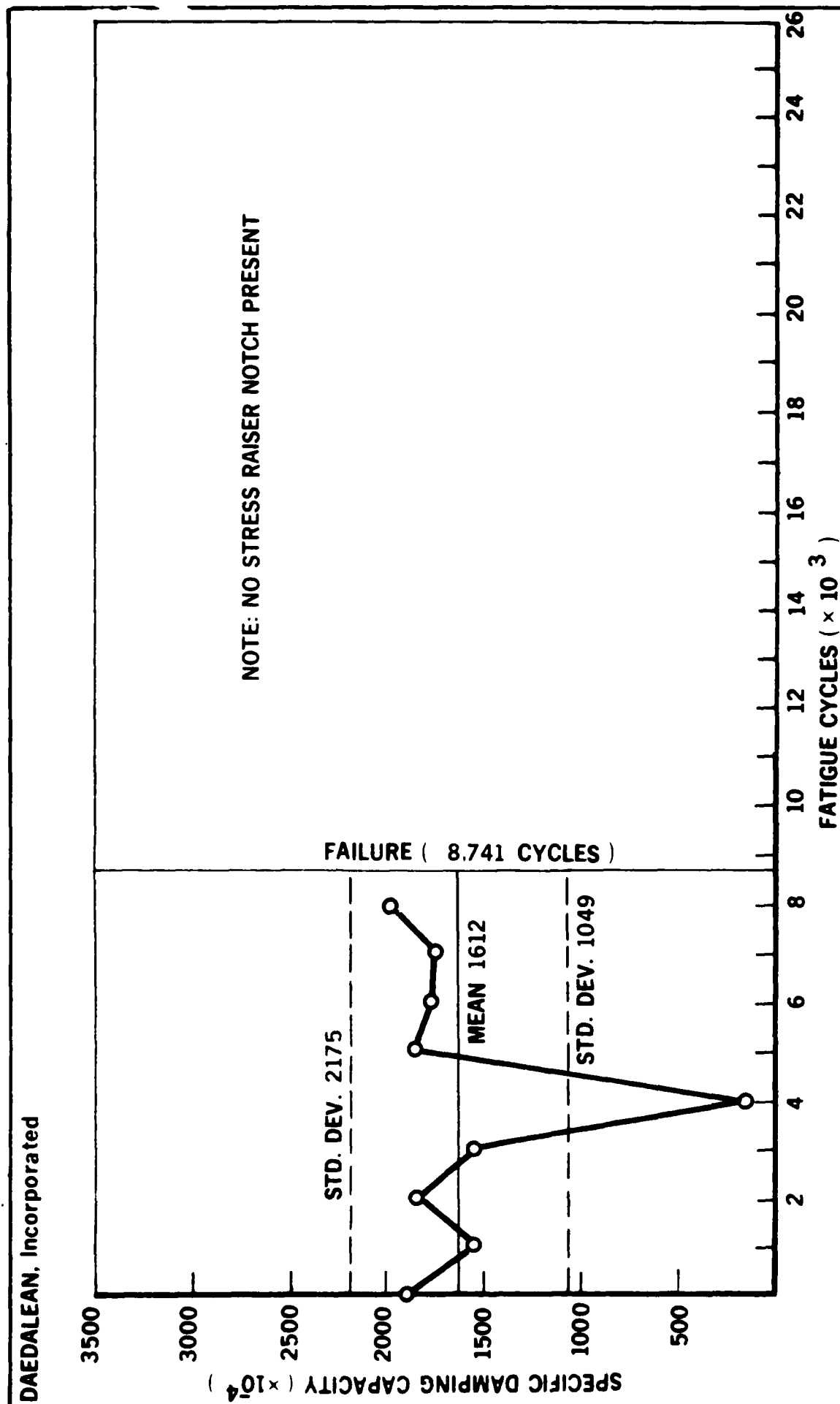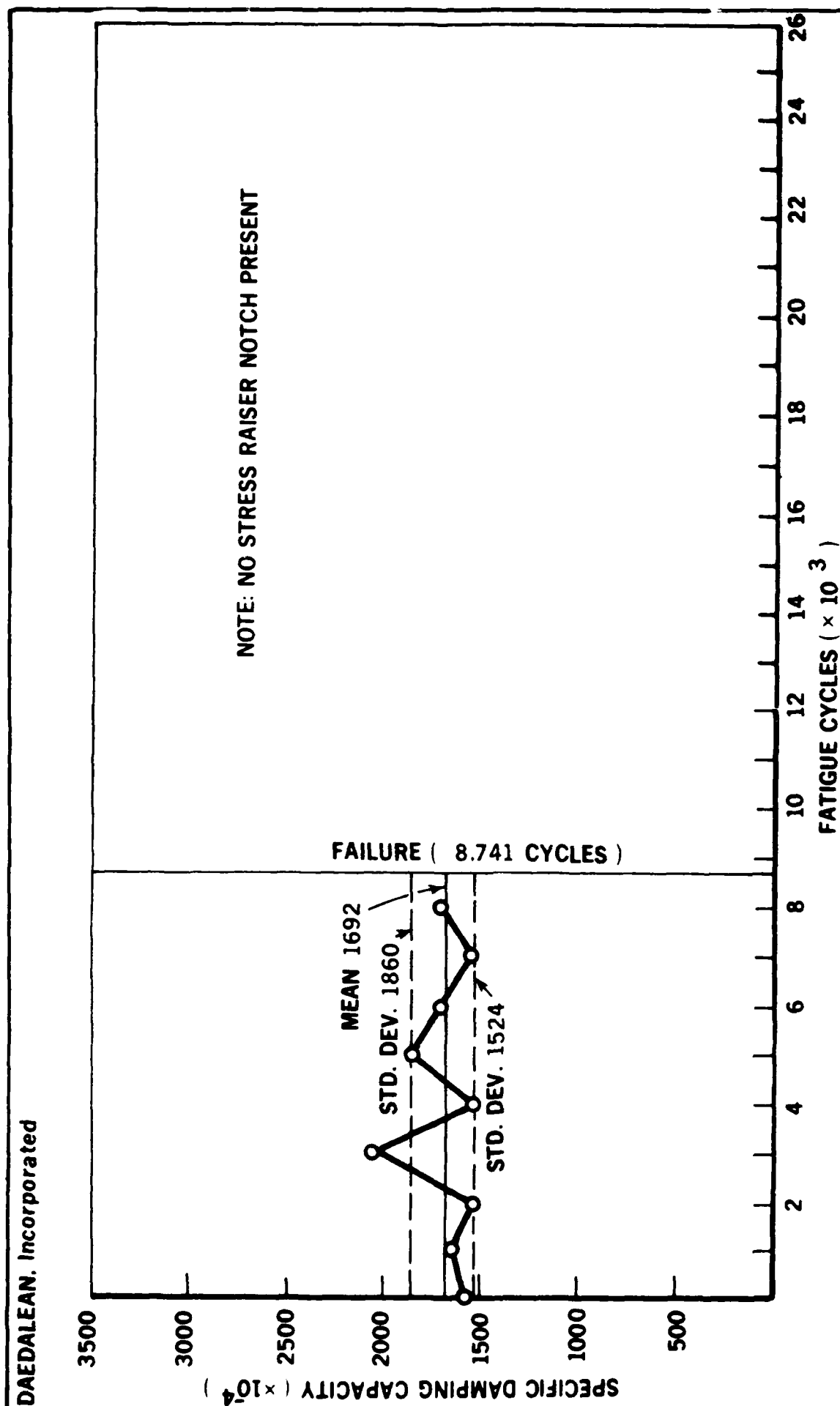
FIGURE 13D MATERIAL: 6061 , SPECIMEN NO: 3, PICKUP POSITION: 4

8409 33

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NOTE: NO STRESS RAISER NOTCH PRESENT

FAILURE (12,000 CYCLES)

MEAN 574

STD. DEV. 627

STD. DEV. 521

SPECIFIC DAMPING CAPACITY (× 10⁴)

3500 3000 2500 2000 1500 1000 500

FATIGUE CYCLES (× 10³)

2 4 6 8 10 12 14 16 18 20 22 24 26

FIGURE 14A MATERIAL: 7005 , SPECIMEN NO: 1, PICKUP POSITION: 1

8409 34

FIGURE 14B MATERIAL: 7005, SPECIMEN NO: 1, PICKUP POSITION: 4

NOTE: NO STRESS RAISER NOTCH PRESENT
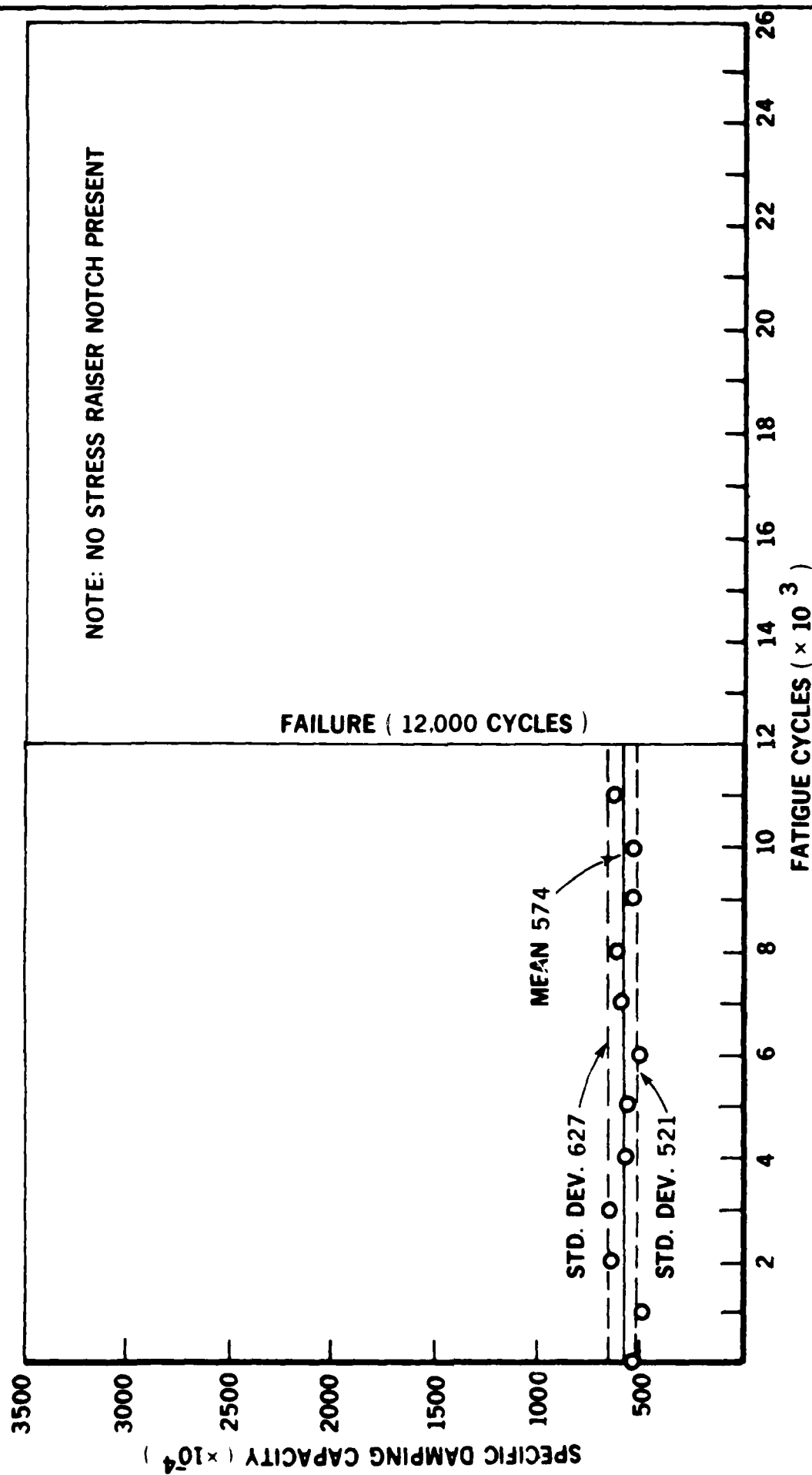
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8409-35

42
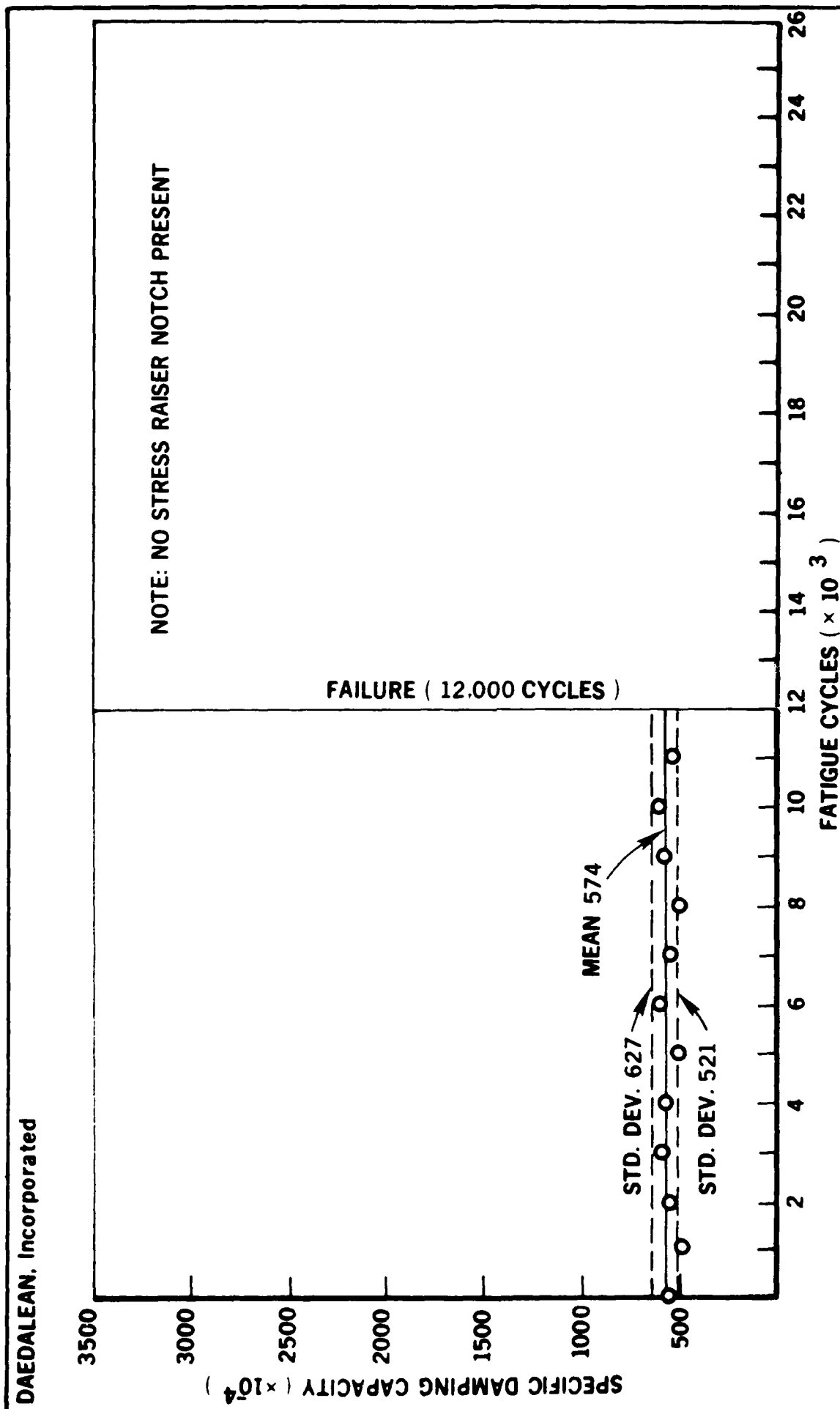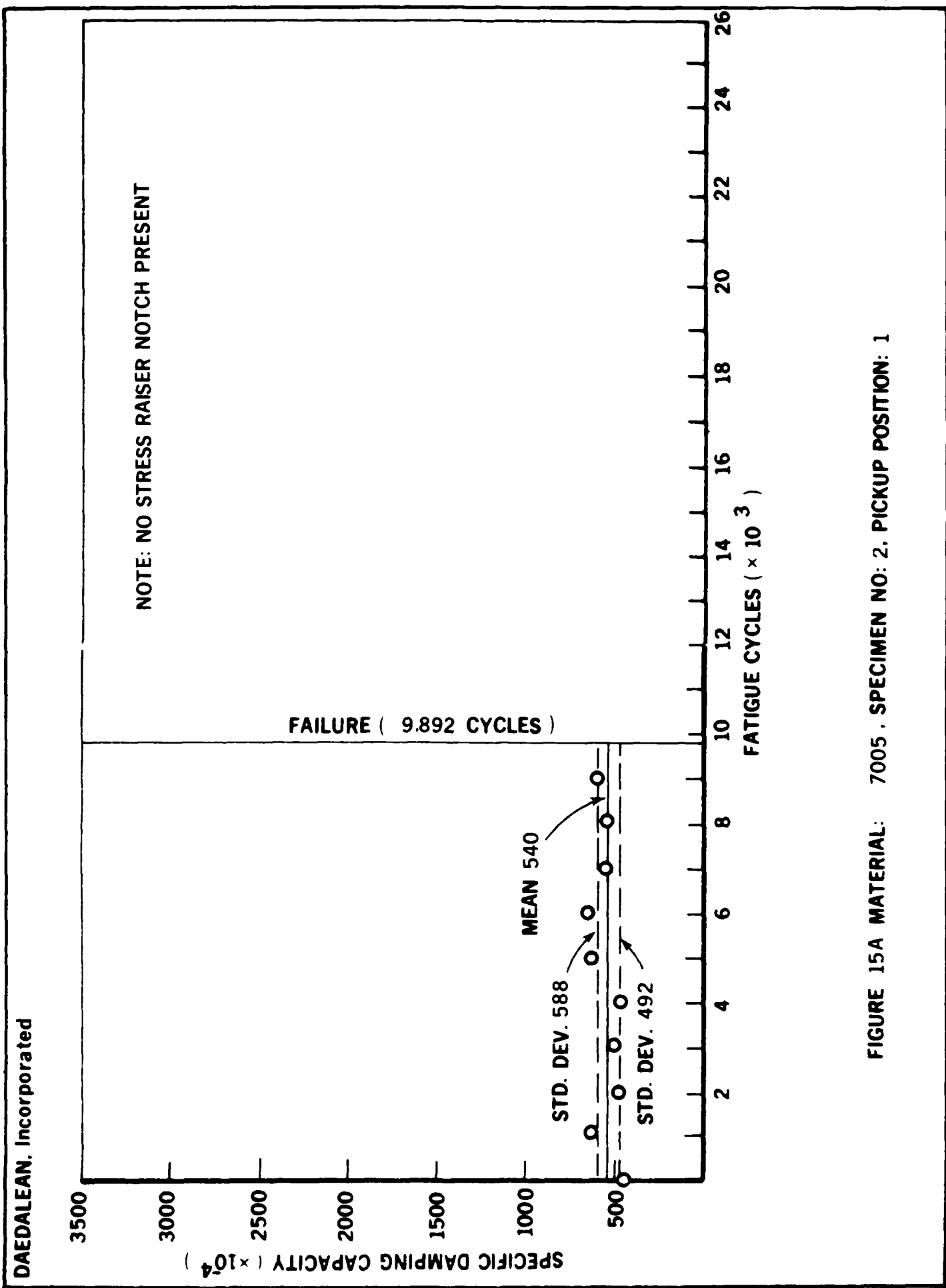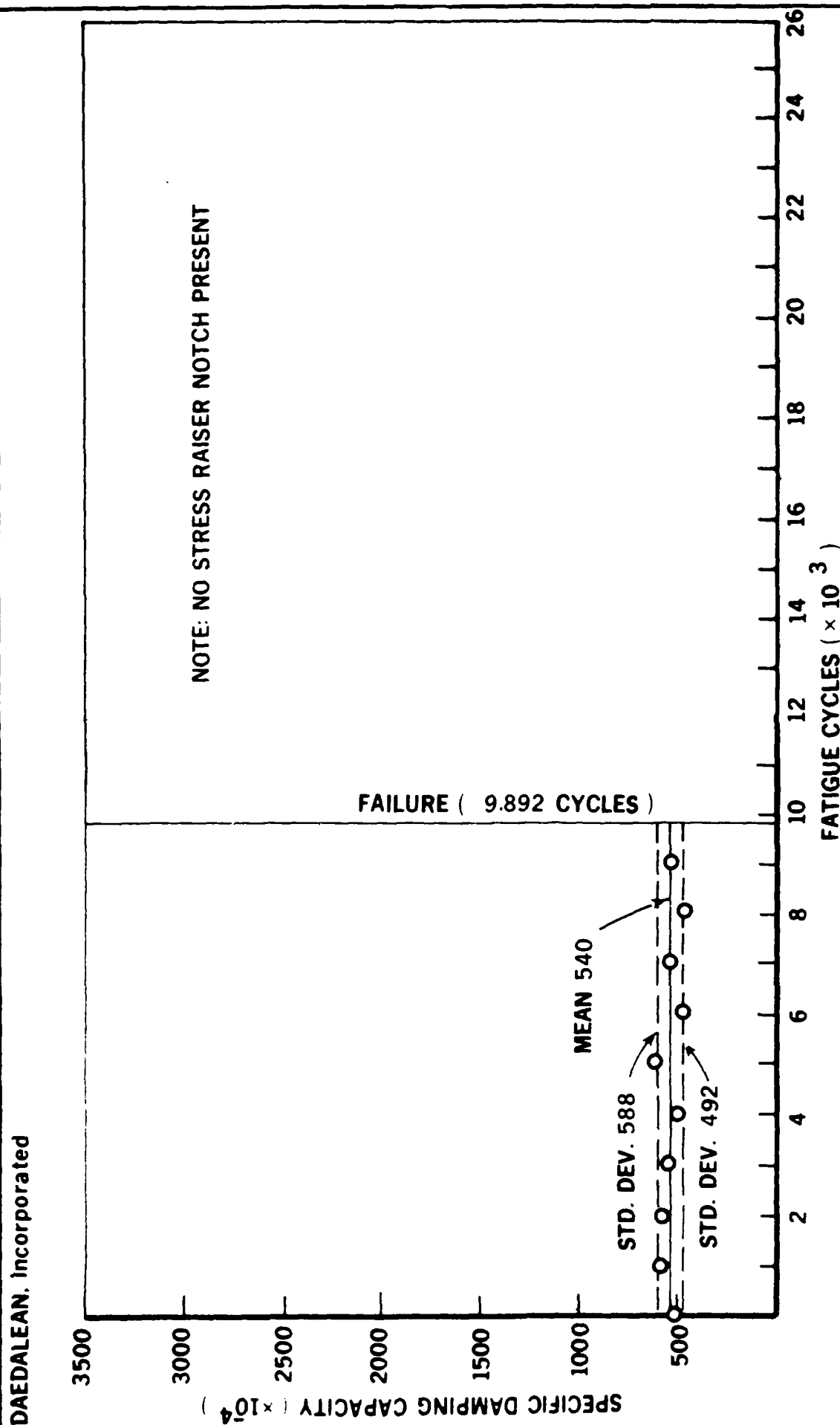
FIGURE 15A MATERIAL: 7005, SPECIMEN NO: 2, PICKUP POSITION: 1

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FIGURE 15B MATERIAL: 7005 , SPECIMEN NO: 2, PICKUP POSITION: 4

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8409-37

4.0 DISCUSSION AND CONCLUSIONS

When employing this technique for ferrous alloys under previous research, it was found that the damping capacity rose gradually but measurably during the first half of the materials life and much more quickly during the last half of the materials life. This made a convenient and reasonably reliable indicator of remaining material life.

This trend was not found in the aluminum alloys investigated under this program however. For all specimens tested the damping capacity remained at a fairly constant if somewhat erratic value. For the 6061 and 7075 aluminum specimens a noticeable spike in the values were noticed for most cases with about 30% remaining material life. No such spike was observed for the 7005 aluminum specimens.

Since the data did not show an increasing tendency over the material life it is not felt that this technique would be a viable test technique for military bridges. This is because, firstly, for those specimens where spike did occur with 30% remaining life, the spike returned to a normal value in a short period of time. In order to detect this spike, on a real structure in the field, a test of the mobile bridge structure would have to be performed on a fairly regular and well documented interval. It is not likely that this would be done under field conditions. Secondly, the 7005 material, which comprises most of the bridge structural components has no failure indicator at all.

5.0 RECOMMENDATIONS

No recommendations are made concerning future work with this NDE technique for the aluminum alloys tested under this program.

6.0   DISTRIBUTION

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